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FUNDAMENTALS OF TELEVISION SYSTEMS.

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DESIGNED FOR A READER WITHOUT SPECIAL TECHNICAL KNOWLEDGE, THIS ILLUSTRATED RESOURCE PAPER EXPLAINS THE COMPONENTS OF A TELEVISION SYSTEM AND RELATES THEM TO THE COMPLETE SYSTEM. SUBJECTS DISCUSSED ARE THE FOLLOWING--STUDIO ORGANIZATION AND COMPATIBLE COLOR TELEVISION PRINCIPLES, WIRED AND RADIO TRANSMISSION SYSTEMS, DIRECT VIEW AND PROJECTION DISPLAY OF TELEVISION IMAGES, AND PHOTOGRAPHIC, DIRECT VIDEO, AND ELECTRON BEAM RECORDING. RADIO TRANSMISSION SYSTEMS DISCUSSED ARE VHF-UHF BROADCASTING AND TRANSLATORS, AIRBORNE AND STAELLITE TRANSMISSION, LASER TRANSMISSION, POINT-TO-POINT AND SATELLITE TRANSMISSION, LASER TRANSMISSION, POINT-TO-POINT FIXED SERVICE. APPENDICES INCLUDE A GLOSSARY AND A SHORT BIBLIOGRAPHY. (BB)

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Fundamentals of Television Systems:

a technical monograph for non-technical personnel

by W. J. Kessler, P. E.

U.S. DEPARTMENT OF HEALTH, EDUCATION & WELFARE
OFFICE OF EDUCATION

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FUNDAMENTALS OF TELEVISION SYSTEMS

by

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February, 1968

EM 000 232

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FOREWORD

This resource paper on the fundamentals of television systems is an attempt to cover the broad field of television in a brief, non-technical manner. The major topics to be discussed are:

1. The conversion of scenes into television signals suitable for wire or radio transmission;
2. Television signal transmission and distribution systems;
3. Television image display or reproducing methods; and
4. Television recording/reproducing methods.

The material presented is intended to be a general treatment for the layman. Therefore, it is hoped that the knowledgeable reader will overlook the absence of a detailed treatment of the more complex topics where such has been deliberately sacrificed in the interest of clarity and brevity.

The author is deeply grateful to the following publications for the use of a few illustrations in this paper:

Figure 7a	Standards of Television Transmission, National Association of Educational Broadcasters, June 1964.
Figure 7b	Television in Education, Sylvania, General Telephone and Electronics, New York, New York.
Figures 10a & 10b	Ibid.
Figure 12	RCA Broadcast News.
Figure 18	Eidophor Sales Brochure.
Figure 19	RCA Catalog.
Figures 23 & 24	Ampex Booklet.

W. J. K.

INTRODUCTION

Ever since man learned to transmit sound over telephone wires and radio systems, he dreamed of the day when he could also transmit pictures to accompany the sound. After decades of technical evolution of numerous crude and relatively unsophisticated approaches to the problem, the modern television system now in widespread use was developed. It is the objective of this paper to offer a simple non-technical explanation of the essential components of a television system and to relate those components to the complete system.

The fundamental building blocks of a complete television system consist of the following four elements:

1. The Origination Facility

   The basic function of the origination equipment is to convert the picture or scene into analog electrical signal variations suitable for transmission over wire or radio circuits. In this paper the term, "radio," will be used in the general sense to mean the transmission of intelligence -- either audio or video -- via electromagnetic radiations without the use of wires.

2. The Transmission Facility

   The transmission facility may consist of either wires, in the form of a suitable coaxial cable, or a wireless radio circuit to transport the picture information signals from the origination point to the destination point or points.

3. The Reception/Display Facility

   The reception/display facility is the final link in the complete system and is, of course, the "black box with the cyclops' eye" which converts the received signals into an accurate representation of the picture or scene at the origination point.

4. The Recording/Reproducing Facility

> Although not necessarily an essential link in a television system per se, the recording and reproduction of pictures or television signals for subsequent use with a television system has become an essential parallel function at the origination, as well as the destination, point.

Figure 1 illustrates a so-called "system flow diagram" which shows schematically the sequence in which the four fundamental building blocks are put together to form a complete system. The usual supporting equipment necessary for operation of such a system -- power supplies, switchers, audio equipment, distribution amplifiers, etc. -- have been deliberately omitted in the interest of clarity.

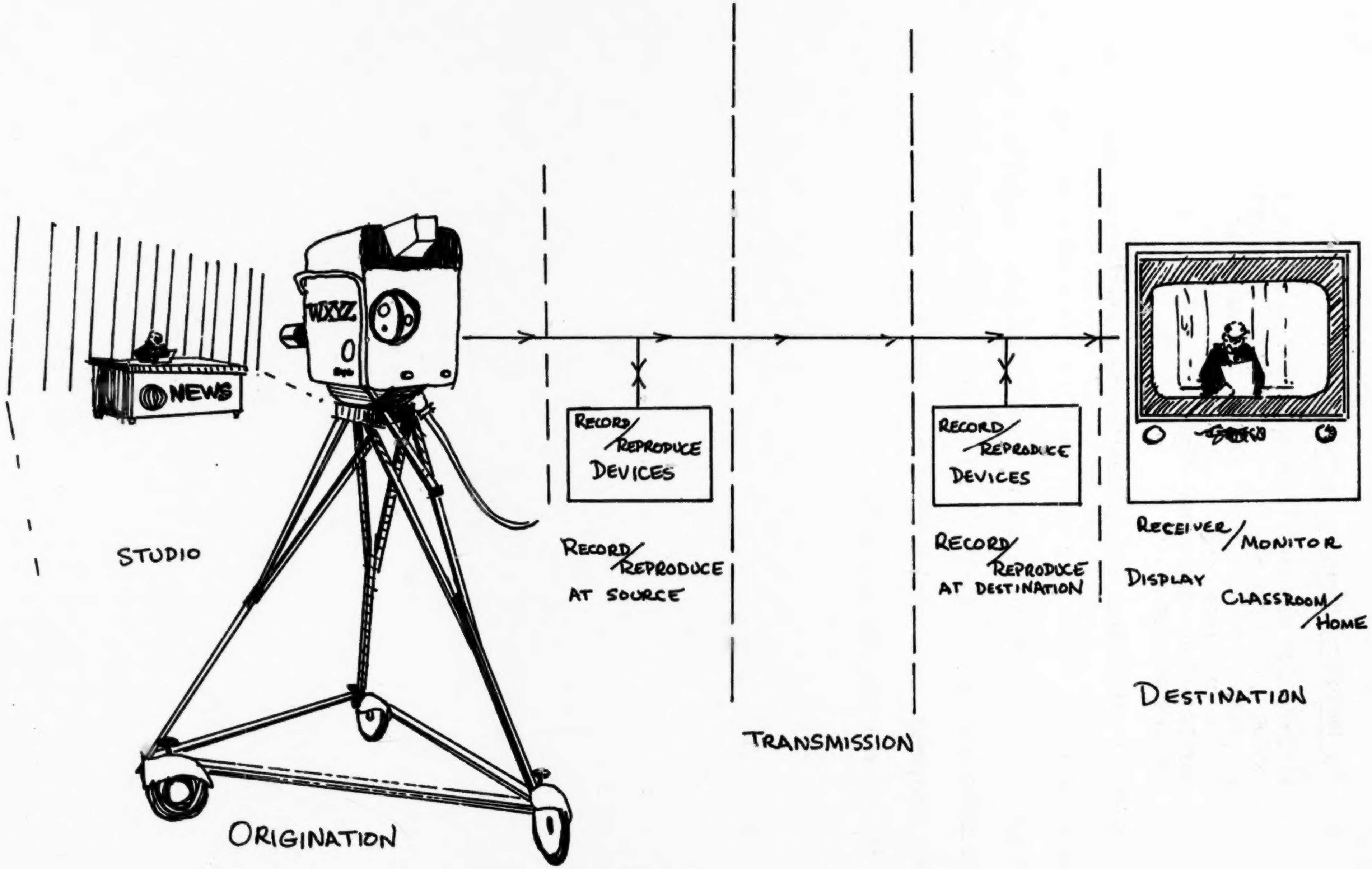

WXYZ
NEWS
STUDIO
ORIGINATION
RECORD/REPRODUCE DEVICES
RECORD/REPRODUCE AT SOURCE
TRANSMISSION
RECORD/REPRODUCE DEVICES
RECORD/REPRODUCE AT DESTINATION
RECEIVER/MONITOR
DISPLAY
CLASSROOM/HOME
DESTINATION

FIGURE 1

THE FUNDAMENTALS OF TELEVISION

An easily understandable explanation of how a modern television system transmits pictures of images from point A to point B (or multiple points) may be given by reviewing man's early attempts to transmit images over telephone wires.

One of these early attempts, devised by C. R. Carey of Boston in 1875, was, in essence, an electro-optical copy of the human eye. A mosaic of photocells (which convert light energy into electrical energy) corresponded to the retina of the human eye; the multi-conductor cable interconnecting the photocells and the light-bulb matrix was an imitation of the optic nerve; and the light-bulb matrix (where the reproduced image appeared) corresponded to the brain. Figure 2 illustrates this system, which may be labeled "simultaneous" or "all-at-once," and the human eye (retina, nerve and brain) model which inspired it.

In this elementary simultaneous television system light from the subject is focused by a lens to form an image on a bank or mosaic of photoelectric cells. Each photocell delivers an electrical current whose magnitude is directly proportional to the amount of light incident on the photocell. This action is similar to the behavior of the rods and cones in the retina of the eye which produce a neuron action potential, or "nerve current," when stimulated by light. The absence of light on the photocell mosaic corresponds to shadow areas in the image and no current is produced in these areas. Conversely, the brightest highlight in the image produces

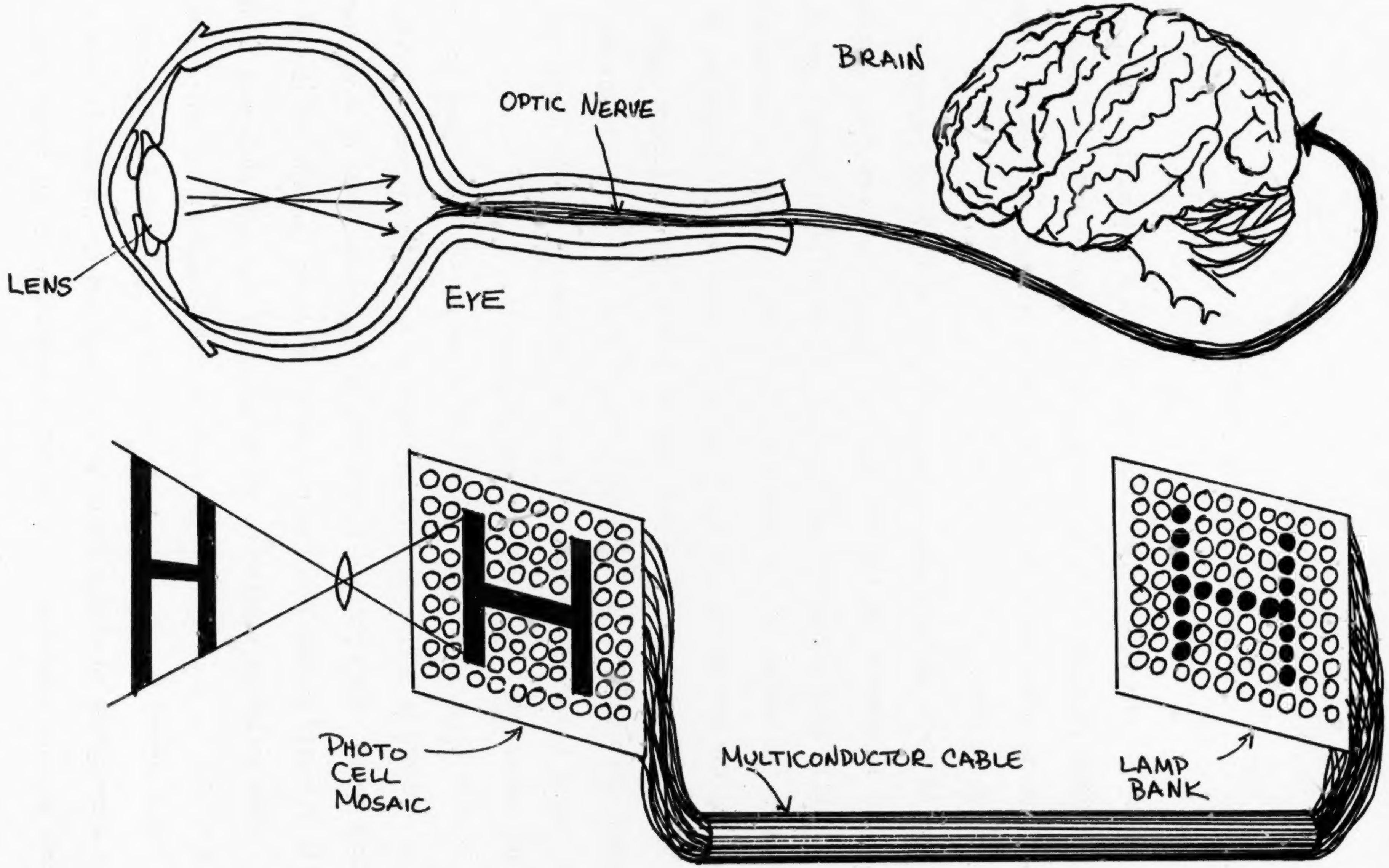

BRAIN
OPTIC NERVE
LENS
EYE
PHOTO CELL MOSAIC
MULTICONDUCTOR CABLE
LAMP BANK

FIGURE 2

maximum current output. A separate pair of wires, or circuit (one for each photocell and corresponding lamp), is required to connect each photocell to a lamp which occupies the same relative position in the image-producing matrix. The early Carey system, although quite workable, exhibits at least two obvious limitations: 1) a very large number of miniature photocells at the origination point and lamps at the receiving point (approximately 100,000 or more) would be required to reproduce an image of acceptable detail; and 2) a separate circuit is required for each photocell-lamp to transmit the electrical signal levels corresponding to the shadows and highlights of each part of the picture.

A giant step forward was taken when early investigators substituted a single circuit, such as one pair of wires or a coaxial cable, for the huge multi-conductor cable by pressing into use another well-known property of the human eye -- the persistence of vision. Because of this characteristic -- the ability of the retina-brain system to store stimuli for short periods of time -- it is not actually necessary to transmit all of the picture elements simultaneously. Thus, it is possible to transmit the individual picture elements in sequence over a single circuit. It is necessary only to display the received picture elements in the same sequence of transmission in the proper position in the receiver mosaic. This must be done rapidly enough so that the eye sees all of the individual elements as a complete picture.

This storage property of the eye is readily demonstrated by projecting a light beam on a darkened wall or screen and rapidly moving the beam from side to side. Thus, one sees a horizontal line instead of what it really is -- a rapidly moving spot of light. This simple well-known optical phenomenon is the fundamental basis of modern television.

Figure 3 illustrates a modification in the original simultaneous system shown in Figure 2 when the multi-conductor cable is replaced by a single coaxial cable. By rapidly switching the originating end of the coaxial line consecutively to each photocell and synchronously connecting the receiving end of the single coaxial line to each corresponding lamp in the lamp mosaic, the eye can be deceived into seeing a complete image on the lamp bank. However, the complete switching cycle must be completed in a space of time less than the persistence of vision interval. The sequence described in this illustration is the rapid image dissection and image-reconstitution achieved through a high-speed sampling or scanning technique.

This high-speed sampling technique is the fundamental principle of modern television: rapidly scanning the picture elements in a systematic manner, transmitting the electrical current variation corresponding to each picture element sequentially over a single channel, and the reconversion of the receiver current variations into light elements at the receiver to reproduce the picture.

However, the final refinement of producing pictures of adequate detail, or resolution, in a practical manner remains to be examined. This is accomplished by a highly mobile electron beam of very small diameter in the modern camera pickup tube.

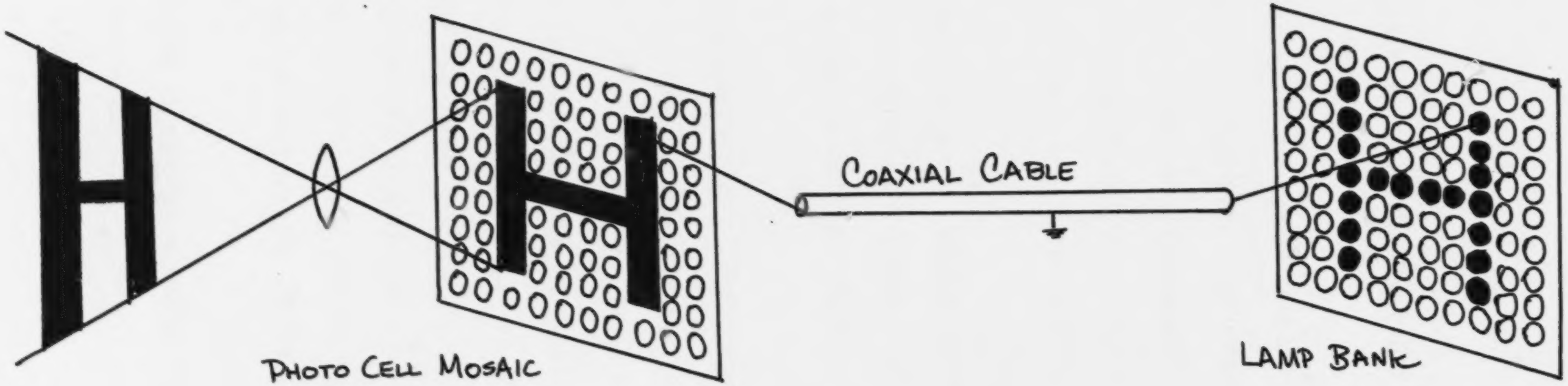

COAXIAL CABLE
PHOTO CELL MOSAIC
LAMP BANK

FIGURE 3

THE STUDIO ORIGINATION FACILITY

In the television studio, where the origination facility is located, the scene to be transmitted must be converted to electrical signals suitable for wire or radio transmission to the destination point (reception/ display) so that these signals can be converted into a replica of the studio scene by the television monitor or receiver. This is the function of the television camera.

In a modern television camera, the crude, coarse-grained mosaic of photocells is replaced by a pickup tube which contains either a single photo-conductive plate (vidicon type) or a photo-emissive surface (image-orthicon type).

The scene to be transmitted is projected optically by a lens onto this plate to form either an optical (vidicon) or an electron (image-orthicon) image as shown in Figure 4.

Every part of this image is then sampled in a precise systematic manner by a very thin stream of electrons known as an electron beam. This systematic process of sampling is known as "scanning." The scanning pattern is from left to right and from top to bottom in a manner identical to the movement of the eye as this page is read. In order to permit the transmission of motion smoothly, the process is repeated (or the image is scanned) 30 times per second.

The rate at which the complete picture is sampled, or scanned, brings up the question of picture flicker, which was a common problem in early motion pictures as well as in many home movies today. At the light

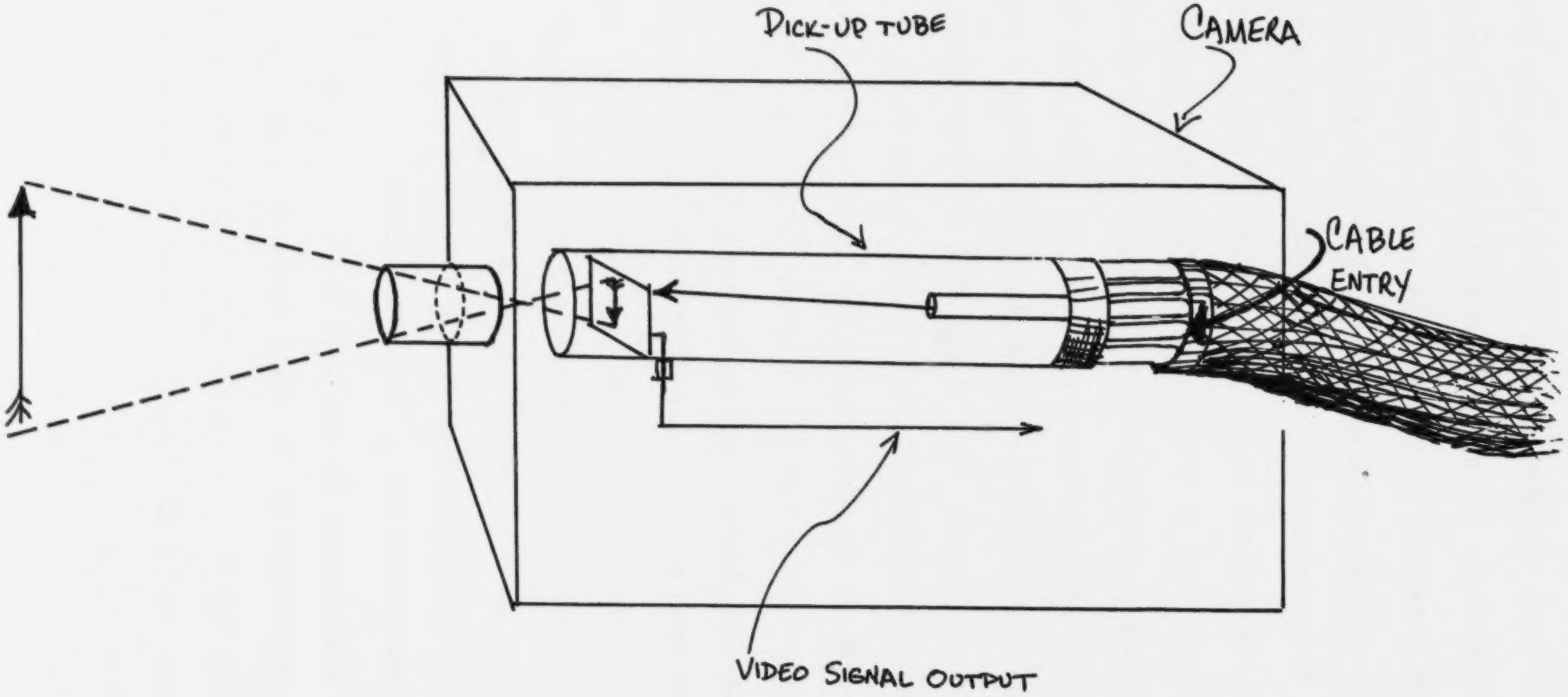
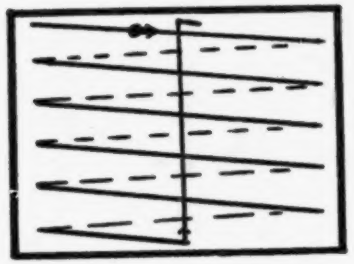
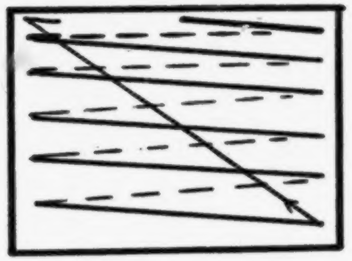

PICK-UP TUBE
CAMERA
CABLE ENTRY
VIDEO SIGNAL OUTPUT

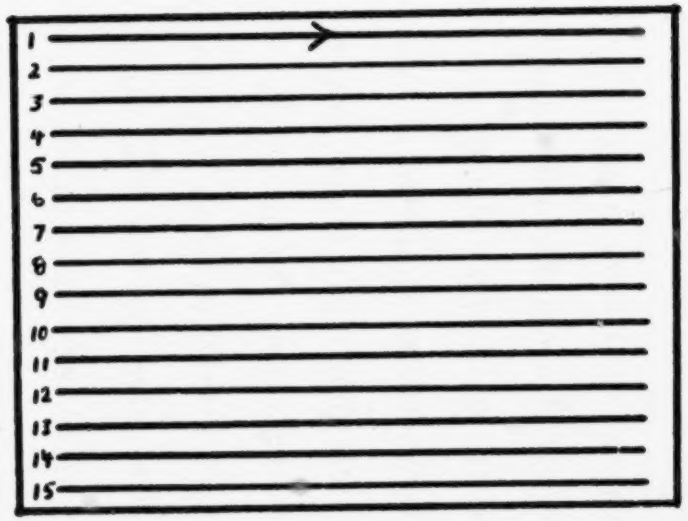
FIGURE 4

levels normally used, the scanning rate should be at least 45 complete pictures (or frames) per second. Modern motion pictures are projected at a rate of 24 frames per second, but the actual flicker rate is 48 per second to avoid any suggestion of picture flicker at all projected light levels. This is accomplished by using the rather clever technique of interrupting the light source in the projector while the picture is being projected on the screen, so that each stationary frame is interrupted, in addition to the usual interruption by the shutter during the short interval when the next frame is pulled into position. Thus, the flicker rate is doubled from 24 per second to 48 per second with only a very slight loss of picture brilliance. This slight loss of picture brilliance can be readily compensated by slightly increasing the intensity of the projection light source. The only other alternative would be to project 48 pictures per second instead of 24 per second, which would obviously double the film footage and, hence, the film expense.

Television faces a similar flicker problem. Thirty complete scans per second are inadequate to avoid all sensation of flicker for the viewer at high light levels. Increasing the scan rate would also increase the frequency spectrum space, or bandwidth, which would needlessly waste a valuable limited commodity by reducing the numbers of channels available to one-half of what we now have. Therefore, television systems make use of a technique that doubles the apparent flicker rate without doubling the spectrum space requirement by modifying the scanning pattern. Thus, instead of scanning from left to right and down as writing is scanned by the eye in the normal reading process, the scanning pattern is alternated as shown in Figure 5.


1st FIELD


2nd FIELD



The elementary scanning pattern begins at the upper left-hand corner scanning with uniform speed to the right, returning suddenly to the left to repeat the process through each adjacent line in the numbered sequence shown in a manner identical to the movement of the eye as this paragraph is read.

READ CAPITALIZED LINES FIRST
THEN INTERLEAVED LOWER-CASE LINES.

THE INTERLACED SCANNING PATTERN DIFFERS
second pass, the even-numbered paths are
FROM THE ELEMENTARY PATTERN IN THAT ONLY
scanned in a manner identical to the movement
THE ODD-NUMBERED PATHS ARE SCANNED DURING
of the eye as this "interlaced" paragraph is read.
THE FIRST PASS (1st FIELD) SO THAT DURING THE

FIGURE 5

The complete image is now scanned in two steps: the first scan covers the entire scene, but skips alternate lines, so that the second scan picks up the alternate lines skipped by the first scan. Thus, two incomplete "half scans" constitute a whole scan. Each half scan is referred to as a "field" and the two fields constitute one "frame." This scanning technique, known as "interlacing" (2:1 locked interlace, to be precise), doubles the apparent flicker rate from 30 per second to 60 per second at only a slight increase in circuit complexity and no increase in spectrum space requirements!

It should be noted here that television broadcast transmission requires the use of one 2:1 locked interlace. Many industrial television cameras, intended for closed-circuit application, make use of what is termed "random interlace." In random interlace the scan for the second field frequently overlaps the first, thus reducing the vertical detail rendition (or vertical resolution) to one-half of that obtainable with locked 2:1 interlace for short periods of time.

A great deal more could be written about television cameras and associated studio origination equipment. At this point, it is only necessary to recognize that the television camera is merely a "black box" which converts the image to be reproduced at a remote location into a sequential electrical signal suitable for wire or radio electrical radiation transmission. An alternate, and more sophisticated, view is that the camera serves to convert a changing three-dimensional scene (two space dimensions and one time dimension) into a two-dimensional variable (video signal amplitude and time) so that it becomes suitable for wire or radio transmission.

However, before proceeding to the various methods of transmitting or distributing this electrical signal representing serialized picture information, it may be well to compare some of the essential characteristics of television cameras employing vidicon or image orthicon pickup tubes. A brief and concise, although non-quantitative, comparison of the significant operating characteristics is made in Table I.

Tube Characteristic	Image Orthicon (3")		Vidicon (1")
Light Sensitivity	Good		Inferior to Image Orthicon
Speed of Response	Good		Noticeable Smear
Grey Scale Rendition	Poor		Good
Noise Level	High		Low
High Light Level Tolerance	Easily Damaged		Rugged
Life Expectancy	5820 1,000 hrs.	8093AL 5,000 hrs.	10,000 hrs.
Replacement Cost	$1,000.00	$1,800.00	$250.00

Table I

This discussion would be incomplete without a brief statement regarding a new second-generation type of vidicon pickup tube known as the plumbicon.

The plumbicon has been publicized as a new pickup tube exhibiting many of the advantages of image orthicons and vidicons. The plumbicon, in essence, employs a photo-conductive layer of lead monoxide instead of selenium. The chief advantages of plumbicons are: 1) high speed of response and, hence, more freedom from smearing of highlights; 2) improved resolution; and 3) good light sensitivity. Plumbicon tubes show a very linear light sensitivity characteristic and, thus, require gradation (tonal range) correction circuits when used in black and white cameras. Plumbicons have also attained widespread use in the newer color cameras.

Compatible Color Television Principles

In recent years compatible color has literally exploded on the commercial television scene. It is little wonder that educational, community, industrial and medical groups are considering the use of color television as a more effective communications medium. Compatible color television means, of course, that the additional electrical signals which convey color information can be successfully combined with the black and white signals without demanding additional frequency spectrum space, or bandwidth, within the assigned television channel. It also means that existing black and white receivers can provide an undegraded picture when a color signal is available, and that the color receiver will produce a black and white picture when only a black and white signal is available.

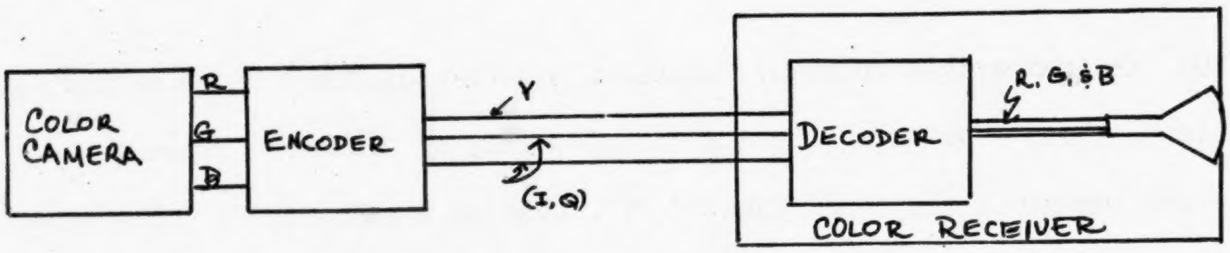
The system designer can meet these requirements in a number of ways. It is well known that white light can be produced by mixing red, green and blue in a particular proportion and that any other color can be obtained by mixing these colors of light in other appropriate proportions. In this case red, green and blue are known as "primary colors." However, it is not universally recognized that red, green and blue are not unique primary colors in that any other three colors may be used if they occupy the same relative position in the Maxwell Color Triangle. Even less well known is the fact that one of the primary colors may be white light provided the other two primary colors are reddish orange and reddish purple (magenta).

Thus, the compatible color transmission system uses these three primary colors; white (including the absence of white, or black) is represented by the luminance component labeled "Y", reddish orange the "I" component, and magenta the "Q" component. The I and Q components are referred to as the chroma signal and may be negative as well as positive in a color television system.

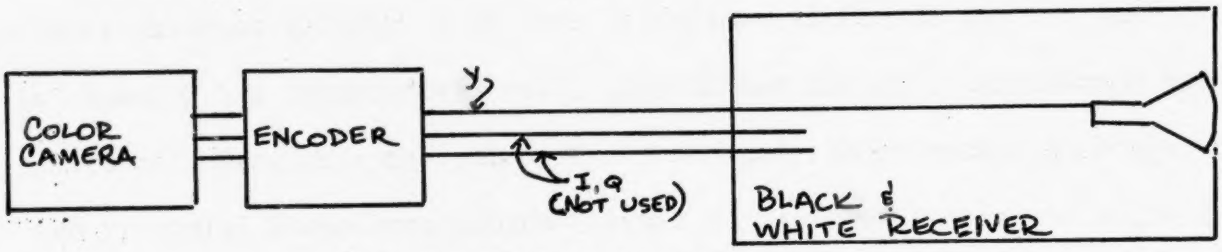
When a color signal is available, the color receiver responds to all three components, Y (black and white), I (reddish orange) and Q (magenta) to reproduce scenes exhibiting the entire color spectrum while the black and white set simply ignores the I and Q chroma components (since it has no circuits capable of handling the chroma signals) and utilizes the black and white Y component only to produce a good black and white picture.

When only a black and white signal is available, the I and Q (chroma) circuits in the color receiver are idle since the I and Q signals are not present and the set responds to the conventional black and white signal (Y component) and produces a black and white picture. In this case the black and white picture is reproduced by the appropriate mixture of red, green and blue. The conventional black and white set produces a black and white picture with either a monochrome or color signal. The four combinations possible with the two types of receivers and two types of signals are illustrated in Figure 6. It may be noted that the Y, or luminance, component is the common denominator of all four possibilities.

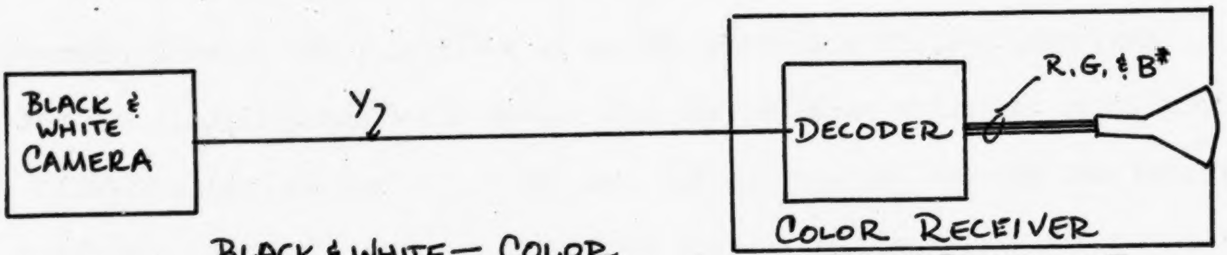
The modern color camera is actually three cameras in one, each of which responds to one of the familiar primary colors -- red, green and blue. The red, green and blue outputs are obtained from three separate pickup tubes equipped with either a red, green or blue filter through which the image is projected into each pickup tube. The electrical


COLOR CAMERA
R
G
B
ENCODER
Y
(I,Q)
DECODER
R, G, & B
COLOR RECEIVER

COLOR — COLOR

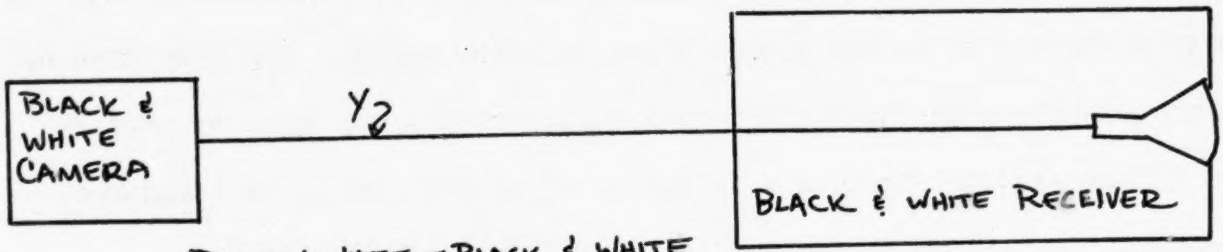

COLOR CAMERA
ENCODER
Y
I, Q (NOT USED)
BLACK & WHITE RECEIVER

COLOR - BLACK & WHITE


BLACK & WHITE CAMERA
Y
DECODER
R, G, & B*
COLOR RECEIVER

BLACK & WHITE — COLOR

* IN PROPER PROPORTIONS TO PRODUCE BLACK & WHITE


BLACK & WHITE CAMERA
Y
BLACK & WHITE RECEIVER

BLACK & WHITE — BLACK & WHITE

Y = LUMINANCE (BLACK & WHITE OR MONOCHROME)
I = REDDISH - ORANGE } (CHROMA)
Q = REDDISH - PURPLE }

* Y (MONOCHROME) = $0.3R + 0.59G + 0.11B$

FIGURE 6

signals, which represent the red, green and blue, are then converted in a circuit called the "encoder" to the Y, I and Q primaries to provide a compatible black and white color signal suitable for transmission and display on either a black and white or color receiver. The color receiver also includes a "decoder" circuit which converts the Y, I and Q components back into the original red, green and blue primaries to reproduce the original scene in color on the face of the tri-color picture tube.

Some available color cameras are essentially four cameras in one -- a conventional black and white camera pickup tube as well as a red, green and blue camera pickup tube.

In these types the conventional black and white channel provides the luminous (Y) channel directly and the red, green and blue outputs are used to provide the I and Q components in the encoder. These four channel cameras may include an image orthicon tube for the black and white channel and vidicon or plumbicon tubes for the red, green and blue channels. Other combinations of orthicons, vidicons and plumbicons are also in use.

TRANSMISSION OF TELEVISION SIGNALS

Since the basic objective of television is to reproduce images and associated sound virtually instantaneously at distant locations, the transmission of the electrical signals corresponding to the picture information is an essential link in the complete system. Two fundamental methods are available: 1) wired systems in which the audio and video signals are conducted from the point of origin to the destination point or points and 2) radio systems in which the video and audio signals are combined and converted to a form suitable for radiation as electromagnetic waves (radio in its general meaning) in all directions (broadcasting) or to a single specific location (point-to-point transmission).

Both wired and radio systems must exhibit a given minimum transmission bandwidth (frequency response) expressed in cycles per second, or Hz., an abbreviation for Hertz, which is a term for bandwidth recently adopted in the United States to conform with international usage. Bandwidth is simply the arithmetic difference between the lowest and the highest frequency of the electrical signal used to represent a television image to be transmitted.

Because of the high picture detail content and the rapid rate (30 complete pictures, or frames, per second) at which the picture information is transmitted to provide the illusion of smooth motion, a relatively broad frequency response or bandwidth requirement is imposed on any television transmission system. The video bandwidth requirements are directly related to the picture detail, or line resolution, required in the reproduced image. These parameters are related in Figures 7a and 7b. The United States broadcast standards, which are a compromise between acceptable picture detail and bandwidth conservation, have limited the maximum frequency of the video bandwidth to slightly less than 4.5 megaHertz, or MHz. A video bandwidth of about 4.2 MHz is the practical limit to avoid interference between the picture and sound signals.

The lower frequency limit is established by the frame frequency of 30 frames per second. This brings the transmission frequency range requirement to the range from 30 Hz. to 4.2 MHz.

As a means of bringing a wide frequency range of 4.2 MHz into perspective, it may be compared to the requirements for various qualities of speech and music transmission.

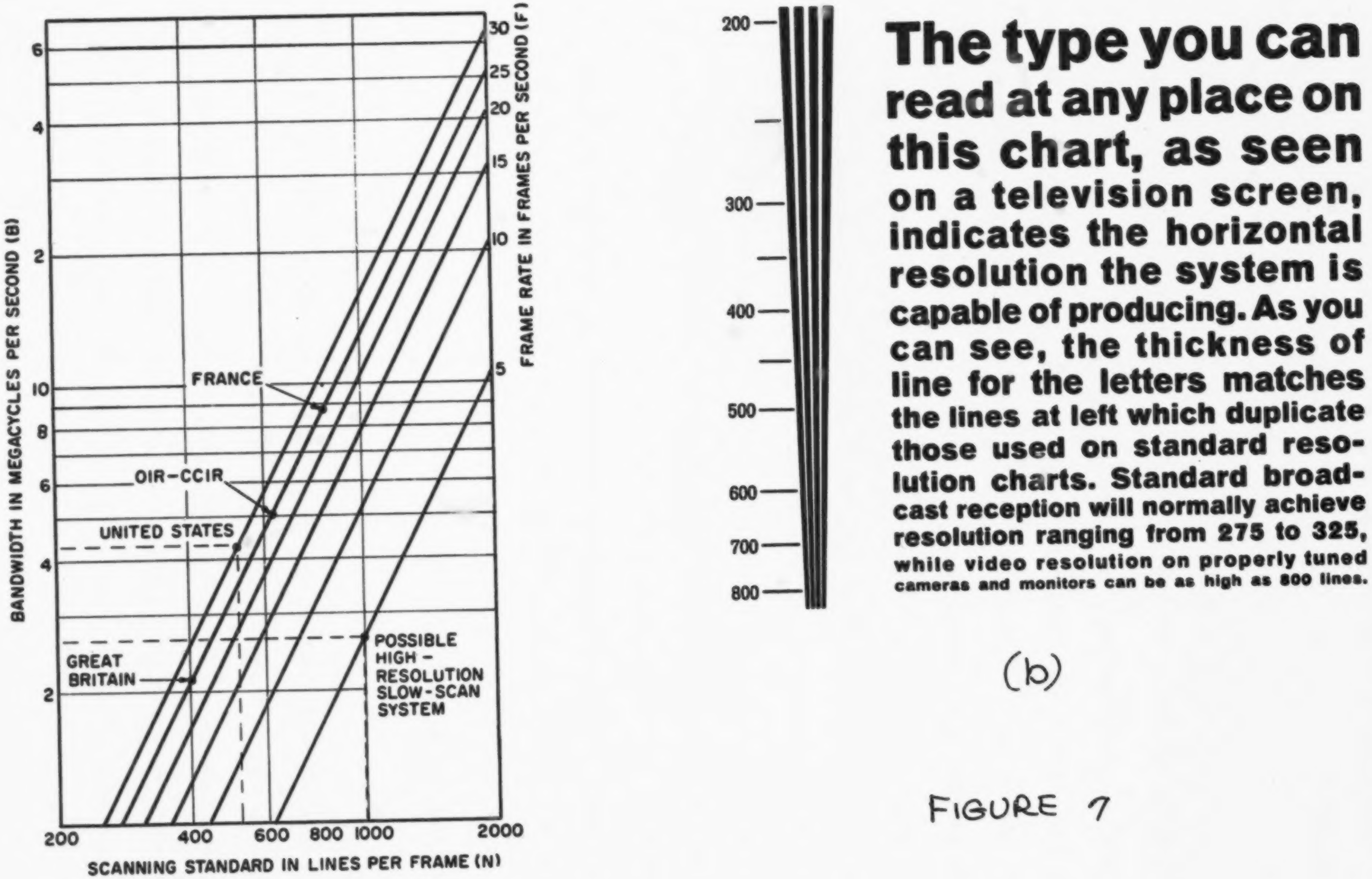
Telephone quality speech transmission requires a range of approximately 3,000 Hz. The television requirement of 4,200,000 Hz. is the equivalent of 1,400 voice circuits!

An AM radio broadcasting network requirement is approximately 5,000 Hz. The 4,200,000 Hz. is equal to 840 AM network programs!

The high-fidelity FM broadcasting network requirement is 15,000 Hz. The television requirement is equal to 280 FM network programs!

Wired Systems

A special conductor known as the coaxial cable, shown in Figure 8, is required to pipe a television program over any significant distance without serious degradation and weakening of the signal. By using special equalizing networks television signals may be "squeezed" through ordinary telephone lines or parallel conductors over very limited distances of a few city blocks.



The type you can read at any place on this chart, as seen on a television screen, indicates the horizontal resolution the system is capable of producing. As you can see, the thickness of line for the letters matches the lines at left which duplicate those used on standard resolution charts. Standard broadcast reception will normally achieve resolution ranging from 275 to 325, while video resolution on properly tuned cameras and monitors can be as high as 800 lines.

(a)

(b)

FIGURE 7

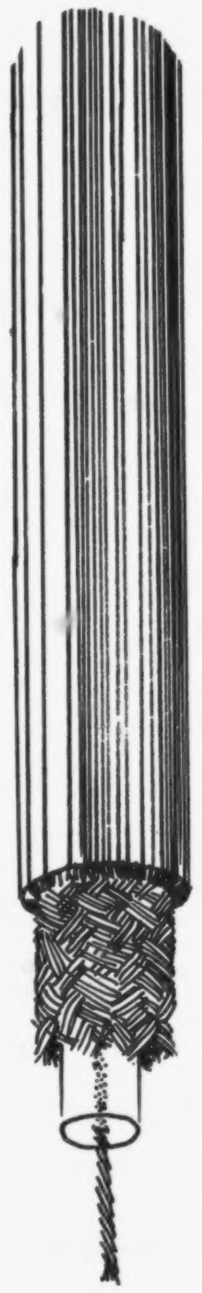


FIGURE 8

In fact, amplifiers to overcome the losses introduced by coaxial cables and cable equalizing networks must be placed at frequent intervals even with a coaxial line system.

With suitable terminal and line amplifier equipment, coaxial cables are capable of transmitting signals from a frequency of zero Hz. (direct current) to a practical upper limit of 10,000 million Hz.!

Coaxial cable transmission systems fall into two basic categories -- direct and carrier transmission.

Direct cable transmission involves the transmission of video signals in the raw form as they emerge from the originating studio. Only the frequency range from 30 Hz. to 4.2 MHz is employed. The associated audio portion is usually transmitted over a pair of ordinary telephone wires generally following the same geographical routes as the coaxial cable.

The direct coaxial transmission method can transmit only one program at a time, requires a separate telephone line for the associated audio, and does not take full advantage of the transmission capability of coaxial cables.

The carrier transmission method involves the mixing, or combining, of the raw video and audio signals originating in the studio with a third signal of a specific frequency referred to as "the carrier." The equipment used in this process is about the size of two ordinary shoe boxes (or one breadbox!) and is a miniature television transmitting station which usually delivers a maximum power output of about three milliwatts. The carrier frequency may be selected to operate on any one of the regular VHF or UHF channel assignments which permits the use of standard television receivers along the cable. This is illustrated in Figure 9.

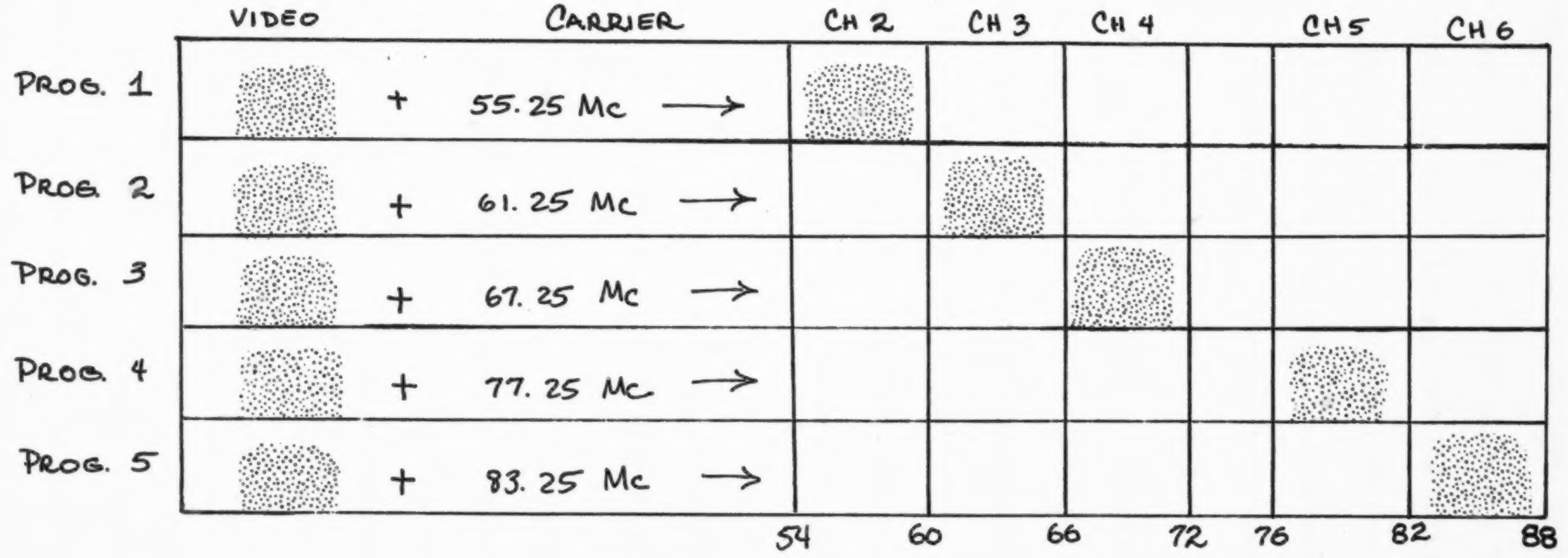

VIDEO
CARRIER
CH 2
CH 3
CH 4
CH5
CH 6
PROG. 1
+
55.25 Mc
PROG. 2
+
61. 25 Mc
PROG. 3
+
67. 25 Mc
PROG. 4
+
77. 25 Mc
PROG. 5
+
83. 25 Mc
54
60
66
72
76
82
88

FIGURE 9

No FCC licensing is required in the broadcasting sense since the miniature transmitter output is not radiated, or broadcast, but merely guided along the interior of the coaxial cable to specific locations. By spacing a number of such carrier frequencies far enough apart to avoid mutual interference (every VHF television channel assignment, for example), twelve separate programs (both picture and sound) may be transmitted to any number of remote locations simultaneously. Any one of the programs may be selected for viewing by changing the channel selector of a conventional television set connected to the cable.

Carrier cable transmission systems, often referred to as "RF systems," are widely used for closed-circuit applications. Two obvious features of such a system are the multiple channel capability over one coaxial cable and no need for separate telephone lines to transmit the associated audio channel.

One well-known commercial application of the carrier cable system is the CATV, or Community Antenna Television Systems.

Radio Transmission Systems

Radio transmission systems fall into the following classifications:

1. VHF/UHF broadcasting
2. VHF/UHF translators
3. Airborne systems (MPATI)
4. 2500 MHz instructional television fixed service (ITFS)
5. Space satellite transmission systems -- orbiting and synchronous
6. Laser transmission systems
7. Point-to-point microwave systems -- studio to transmitter links (STL) and inter-city links

1. VHF/UHF Broadcasting

VHF and UHF television broadcasting is, of course, very well known. Therefore, no detailed description is presented in this treatment other than to summarize a few of the pertinent facts in Table II.

Channel Characteristics	Channel Number	Frequency Range in MHz	Max. Auth. ERP in KW	Approximate Service Range
Low VHF	2	54-60	100	65
"	3	60-66	"	"
"	4	66-72	"	"
"	5	76-82	"	"
"	6	82-88	"	"
High VHF	7	174-180	316	55
"	8	180-186	"	"
"	9	186-192	"	"
"	10	192-198	"	"
"	11	198-204	"	"
"	12	204-210	"	"
"	13	210-216	"	40
Low UHF	14-40	470-632	5000	40
High UHF	41-83	632-890	5000	30

Table II

Channel 1 is missing because the frequency range originally allocated to it (48-54 MHz) was preempted during the early days of television for use by a military high-power ionospheric scatter communications system.

It may be observed that, while the channel numbers are consecutive, the corresponding frequency ranges are not. For example, there is a 4 MHz gap between channels 4 and 5, an 86 MHz gap between channels 6 and 7, and a 254 MHz gap between channels 13 and 14. These frequency gaps are occupied by other communications services such as aeronautical/navigational communications systems, FM broadcasting, and mobile two-way radio (land based).

Table II also shows that the frequency interval, or bandwidth, for each channel is 6 MHz wide. Although less than 4.5 MHz is required for the picture signal, the remaining 1.5 MHz is allocated to the program sound channel and so-called "guard bands" to eliminate interference between the picture and sound signals, as well as adjacent television channels.

A glance at the last column in the table shows the approximate service range in miles. This column should not be interpreted to mean that the service is perfect for all distances from the transmitter less than the quoted service range and that no service is provided beyond the quoted service range. It does mean, however, that less than 50% of the receivers outside this contour are receiving satisfactory service and that the percentage begins to drop rapidly as the distance increases.

2. VHF/UHF Translators

Quite often, due to unusual terrain characteristics or population distribution, an economical means of filling in, or extending, the coverage area of a high-power VHF or UHF station is desirable.

A practical and economical means of providing such additional "spot coverage" of a parent station is by means of low-power satellite stations called translators. Translators are unique in that they merely "translate" the frequency of the parent transmitter to another channel to permit rebroadcasting the program on a very low power of either 1, 10 or 100 watts. In this way the low-power translator provides a strong signal to the receivers in the weak-signal area because of the close proximity of the translator to the television receivers served.

Translators may be used to rebroadcast VHF stations on either VHF or UHF, as well as for the rebroadcast of UHF stations on UHF.

3. Airborne Transmission Systems

One of the major factors which limit the useful service range of a conventional ground based television broadcast transmitter is the general weakening of the signal caused by energy absorption along the transmitter-to-receiver paths.

During the early days of commercial television, the Westinghouse Electric Corporation engineers proposed an idea in which the television transmitter would be airborne to high altitudes so that all the transmitter-to-receiver paths would be unobstructed. The airborne system was called "stratovision" and was expected to provide service ranges approaching 200 miles in all directions using transmitter powers less than that of its ground-based brothers. The idea -- which was an imaginative one -- just didn't seem to "get off the ground" until September 1961. In that year the Midwest Program on Airborne Television Instruction (MPATI) began its first full academic year.

In the MPATI system instructional program material is broadcast simultaneously on UHF channels 72 and 76 to schools and classrooms within a 200-mile radius from a modified DC-6 aircraft executing a figure eight pattern at 23,000 feet over Montpelier, Indiana.

The DC-6 aircraft is equipped with a 24-foot streamlined retractable antenna which can be lowered from the bottom of the aircraft in flight. The antenna is gyro stabilized so that its vertical position with respect to the earth's surface can be maintained as the aircraft executes the figure eight pattern. Two fully equipped DC-6 aircraft are available, one being on a standby basis.

Each school participating in the MPATI program uses UHF converters with individual antennas oriented toward the general position of the aircraft over Montpelier. If a closed-circuit distribution system is available at a given school, the received program is converted to a VHF channel for in-building distribution to each classroom.

Even though the aircraft broadcasts programs from an altitude of over 4 miles, direct in-school reception difficulties have been experienced in the larger metropolitan areas of Cleveland, Chicago and Detroit. Accordingly, supplementary UHF translator facilities have been placed into operation in the weak signal areas. Reception difficulties have also been experienced directly beneath the position of the aircraft due to the reduced energy radiation from the end of its antenna.

In January 1963 MPATI filed a request with the FCC for a license to operate as a regular airborne service of the instructional television system on six channels simultaneously. After numerous statements were made both in support and opposition to the MPATI proposal, the FCC in March 1966 granted MPATI the authority to operate six channels in the new 2500-2690 megaHertz instructional television fixed service it had established in September 1963.

4. 2500 MegaHertz Instructional Television Fixed Service (ITFS)

For some time educators, industry representatives and the FCC have recognized the need for additional channels dedicated to the use of in-school instructional television. In response to this need the FCC established a new service in the 2500-2690 MHz frequency range which provides a total of 31 television channels for this purpose.

The 2500 megaHertz system is unique in a number of respects:

a. It is a multiple-addressed fixed service rather than a broadcast system and, as such, exhibits many legal and technical features of closed-circuit systems.

b. The system combines many of the best features of point-to-point microwave systems with the operating standards of VHF/UHF broadcasting so that regular VHF receivers may be used in the classrooms.

c. The allocations plan provides for a group of four channels to be assigned to a qualified applicant.

d. The receiving "down-converter," which changes the microwave signal into the VHF signal, converts the entire four channel group together so that only 2500 megaHertz transmitters may be used, as needed, to meet the additional channel requirements.

e. The permissible power output of 2500 megaHertz transmitters, while not specifically limited for all applicants, has been nominally fixed at 10 watts to provide a restricted coverage radius so that the same channel groups could be reassigned to adjacent geographical areas without serious interference effects.

f. No rigid specifications regarding fixed co-channel and adjacent-channel mileage requirements between transmitter installations were made. The allocation of specific channels is based instead on reasonable channel interference criteria, taking into consideration intervening terrain between systems, directional antennas and all other known interference-reducing techniques.

One of the most important aspects of 2500 megaHertz systems is the fact that, although the channels were established exclusively for educational purposes, their use is not restricted to in-class instructional use. The service may also be used for teacher training and school administrative functions.

The complete instructional system consists of four basic units: a) the originating studio facilities, which are essentially identical to the studio requirements of VHF/UHF broadcasting; b) the 2500 megaHertz multiple point-to-point transmission systems, including all the outlying down-converters; c) the in-school coaxial cable distribution system interconnecting the down-converter to the classroom receivers; and d) the classroom television sets which are conventional VHF/UHF receivers which permit selection of any available channel.

The basic layout for a complete 2500 megaHertz ITFS system is shown in Figures 10a and 10b. It will be observed that in such a system the

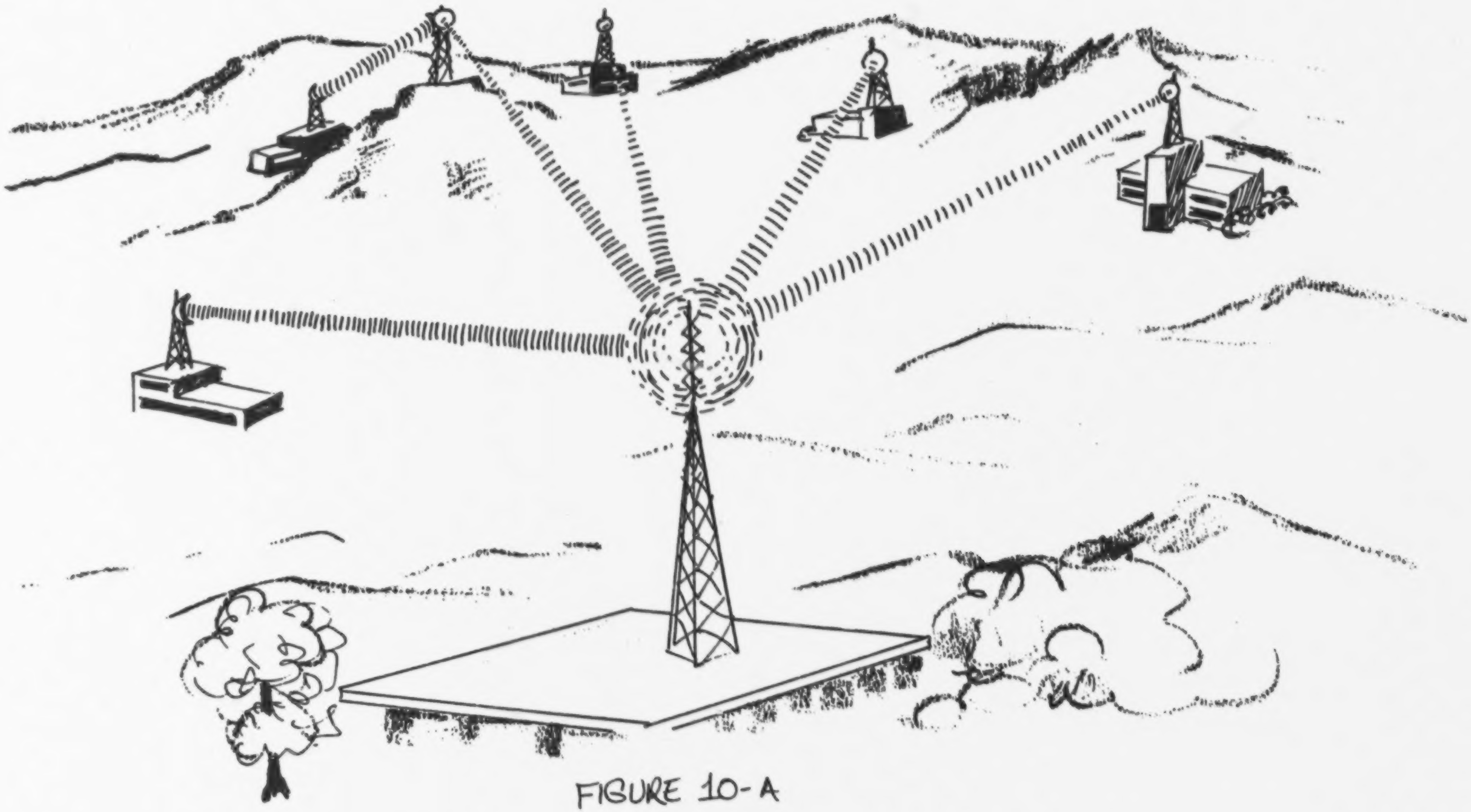


FIGURE 10-A

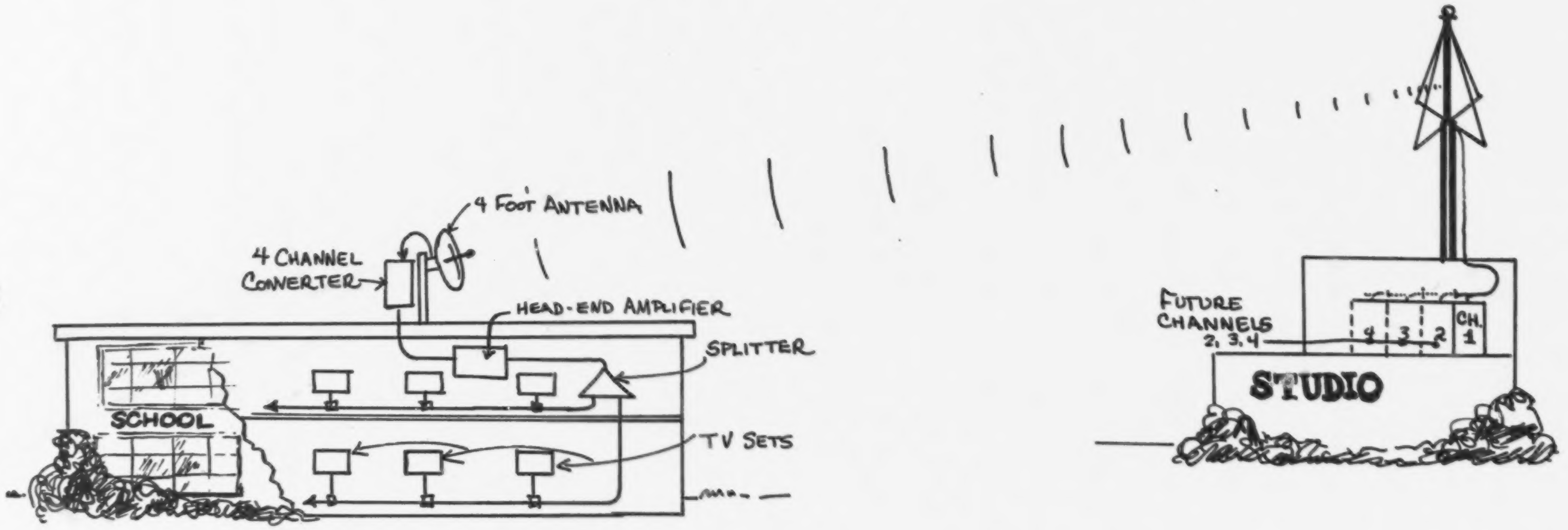

4 Foot Antenna
4 Channel Converter
Head-End Amplifier
Splitter
School
TV Sets
Future Channels 2, 3, 4
4
3
2
CH. 1
Studio

FIGURE 10-B

receiving down-converters are an integral part of the transmission system design to insure good reception. This is generally not the case with either VHF/UHF commercial or educational broadcasting systems.

A copy of the original FCC release giving an authoritative description of ITFS is reproduced in Appendix B. Included also is a brief description of a nationwide committee established by the FCC for the full development of the Instructional Television Fixed Service.

5. Space Satellite Transmission Systems

Space satellite transmission systems (perhaps more accurately labeled "relay systems") constitute the most modern approach to the problem of providing a high-altitude low-power transmitter to extend the useful service range over vast areas of the earth's surface.

Space satellite transmitters fall into two basic categories: orbiting satellites and synchronous satellites.

The orbiting satellite, when used as a space relay platform, is equipped with a compact relay system capable of receiving television signals from any one point on the earth within visual range and rebroadcasting with a power level of about 100 to 200 watts to elaborate ground stations located at other parts of the world. The orbits of such space satellite relays are usually at altitudes of 1,000 miles or more. However, due to the orbiting nature of these relay stations, their position with respect to the fixed ground station is constantly changing, which requires elaborate antenna tracking equipment at the ground station. Furthermore, as a given satellite relay moves out of range of a given area as it orbits the earth, another satellite must move into position to provide continuous relay service. The operation of a system of orbiting satellites to provide continuous service is illustrated in Figure 11. It is estimated that from five to ten relay satellites would be required for uninterrupted service.

Telstar, the first privately owned satellite, was constructed by the American Telephone and Telegraph Company and launched on July 10, 1962, by the National Aeronautical and Space Agency.

Many of the problems of orbiting satellites can be overcome by launching the relay satellite into a higher altitude orbit so that the rotational period increases from about 90 minutes to precisely 24 hours. In this way the relay satellite appears to be stationary since it is orbiting at the same rate as any fixed location on the earth's surface. Such satellites are labeled "synchronous satellites." The critical altitude at which synchronism with the earth rotation occurs is approximately 22,300 miles. With such a synchronous relay satellite, not only is the tracking problem of the ground station antenna eliminated, but the coverage area is increased to about one-third of the earth's surface. In this way only three satellites are required to provide a worldwide transmission system. This is illustrated in Figure 12.

There is little question among knowledgeable authorities that relay satellites of the synchronous, or stationary, class constitute the answer to a future worldwide relay system for all types of communications services.

It should be noted, however, that at the present stage of development, individual home receivers cannot receive satellite transmissions directly due to the rather weak signals available from the distant low-power satellite. There is little doubt that this is only a temporary hurdle which will be surmounted eventually -- perhaps sooner than many authorities now believe.

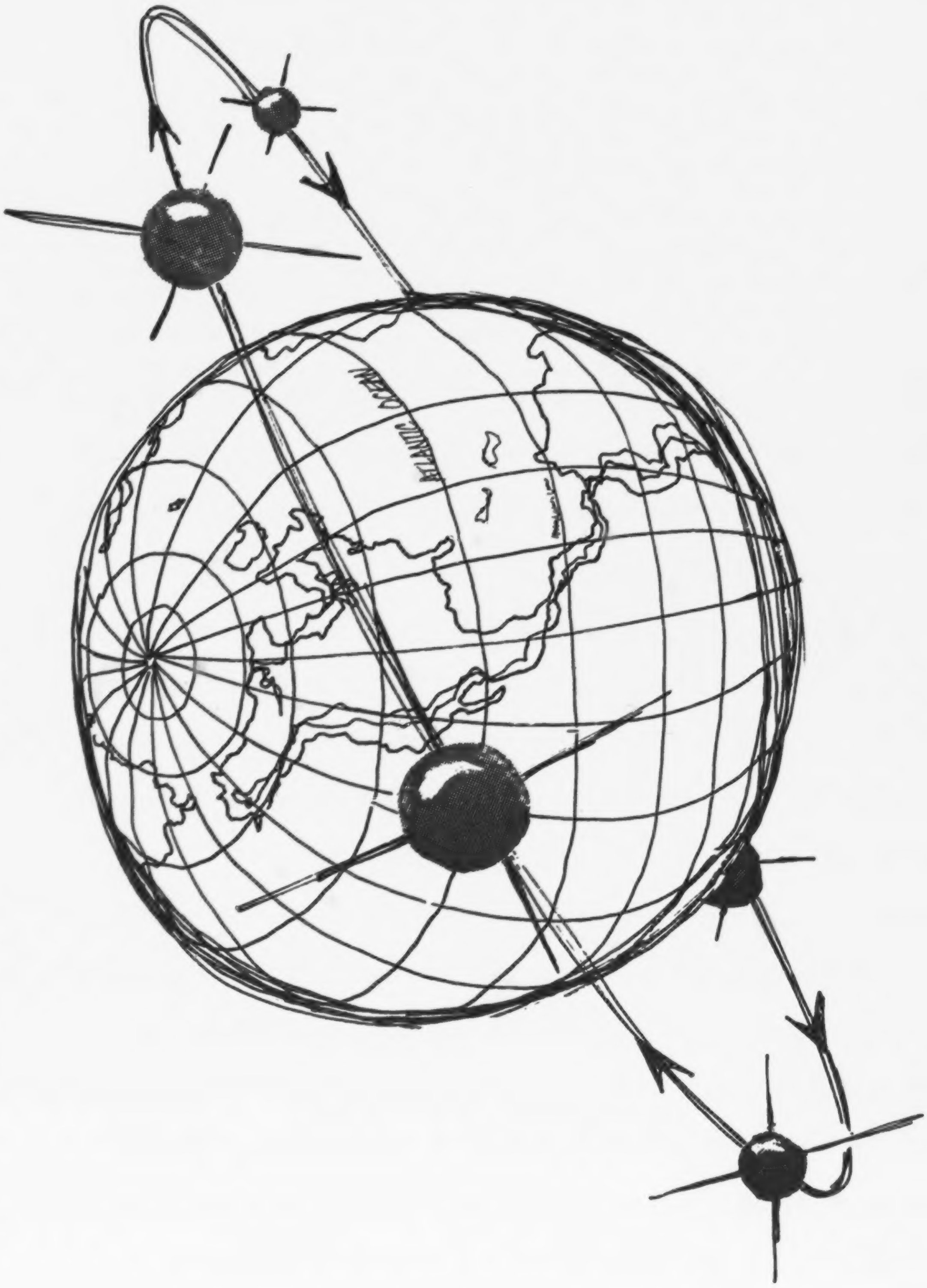

ATLANTIC OCEAN

FIGURE 11

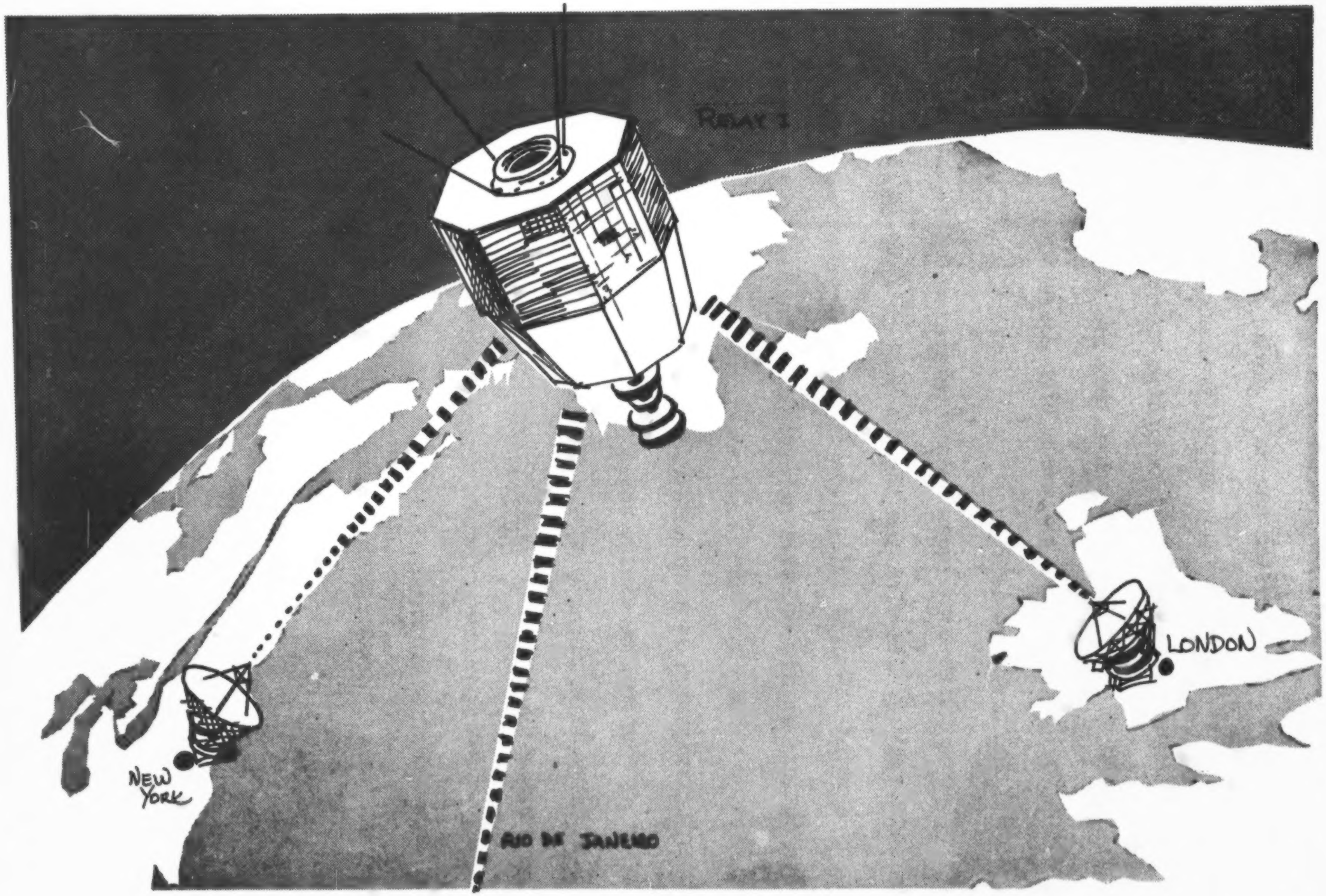

RELAY I
LONDON
NEW YORK
RIO DE JANEIRO

FIGURE 12

6. Laser Transmission Systems

A laser transmission system may be regarded as just another point-to-point carrier system where the carrier frequency is high enough to fall in the visible portion of the electromagnetic spectrum. Laser beams are a different kind of light source because they are generated in a special way and because they attain an extremely high degree of color purity (coherent light) and high intensity.

Only recently have techniques been developed to modulate (or mix) the picture and sound signals with the laser energy so that the laser beam can be used as a point-to-point television transmission system. Laser beams, which are optical in nature, will not readily go around obstructions and are weakened by cloud banks and heavy moisture.

Laser transmission systems hold great promise in outer space where there is no atmosphere, no clouds and no fixed obstructions to weaken the beam. The laser beam, because of its very high operating frequency, exhibits tremendous bandwidth characteristics and, hence, is capable of handling a phenomenal number of simultaneous television channels as well as other communication circuits.

However, laser transmission systems have not yet fulfilled their promise for widespread terrestrial communication applications.

7. Point-to-Point Microwave Transmission Systems

Point-to-point microwave systems belong to the category of radio transmission systems. They differ, however, in two important respects: a) point-to-point microwave systems are intended solely for the purpose of interconnecting originating points and broadcasting stations, and to provide high-quality closed-circuit links between specific locations and

b) modulation standards and allocated channel spectrum widths have been chosen to provide the highest possible transmission characteristics so that the interconnecting links contribute essentially no degradation to the reproduced image.

Point-to-point microwave systems fall into two general classifications -- studio-to-transmitter links and multi-hop inter-city links.

Studio-to-transmitter links (STL) are usually one-hop links which provide for the transmission of the picture and sound program from the originating studio to the broadcasting plant.

Microwave systems always employ parabolic reflecting transmitting and receiving antennas so that the transmitted microwave energy, which serves as the picture/sound information carrier, can be focused into a sharp beam towards the receiving antenna.

Quite often a periscope technique is used in which the parabolic antenna (referred to as a "dish") is oriented so that the beam is vertical and a flat metal plate installed at the top acts as a reflector to change the direction of the beam. These two methods, with and without the passive reflector, are shown in Figure 13.

Multi-hop microwave links, whether used for inter-city STL purposes or closed-circuit interconnections, employ relay stations spaced an average distance of about 25 miles apart, as shown in Figure 14.

When the total system is less than about 100 miles, so that a maximum of three relay stations are required, the relay station may consist of a microwave receiver connected directly to the input of a microwave transmitter. Such a relay is called "back-to-back" and invariably introduces degradation of the signal available at the end of the system.

When the length of the inter-city relay system exceeds 100 miles (or is transcontinental, such as the American Telephone and Telegraph

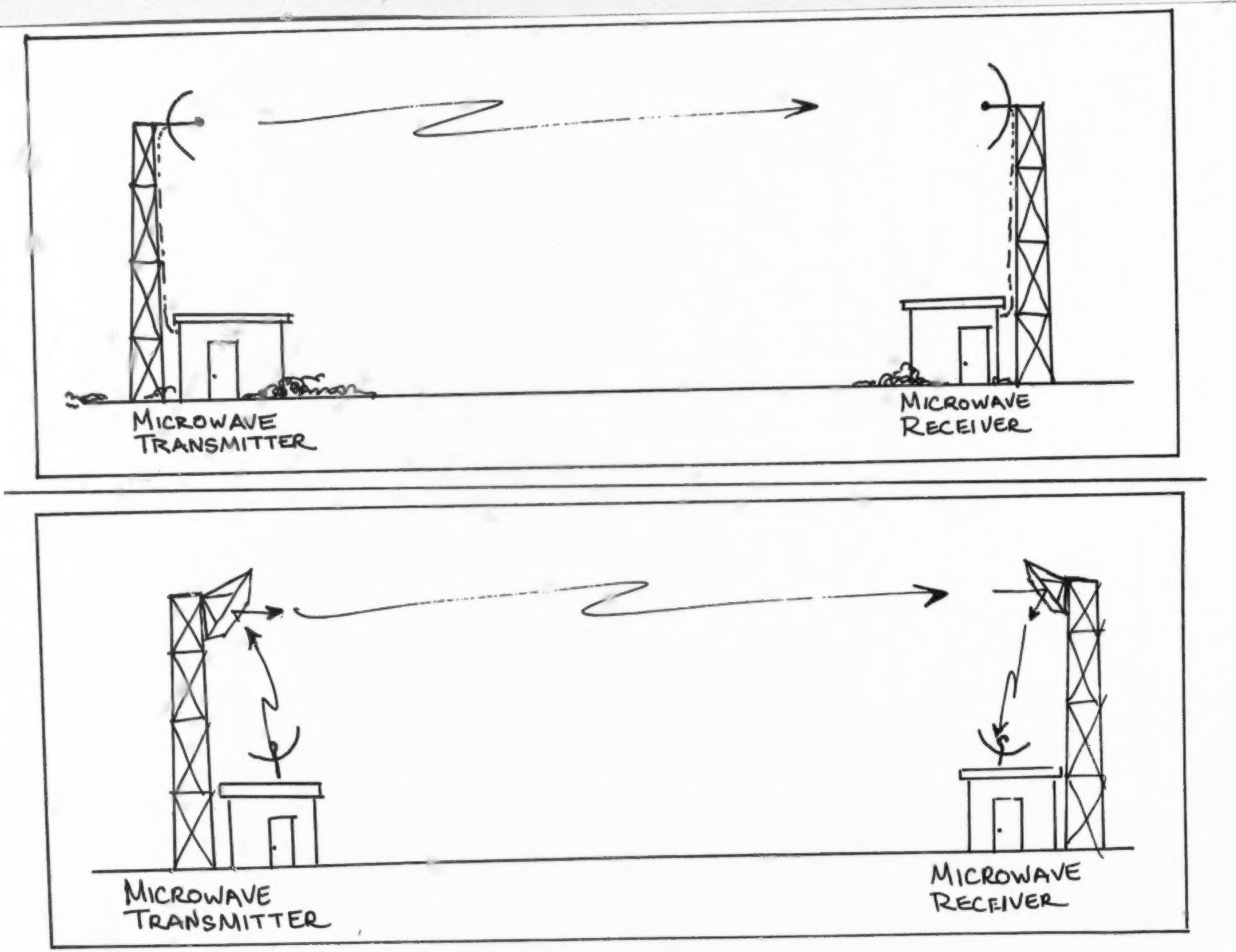

MICROWAVE TRANSMITTER
MICROWAVE RECEIVER
MICROWAVE TRANSMITTER
MICROWAVE RECEIVER

FIGURE 13

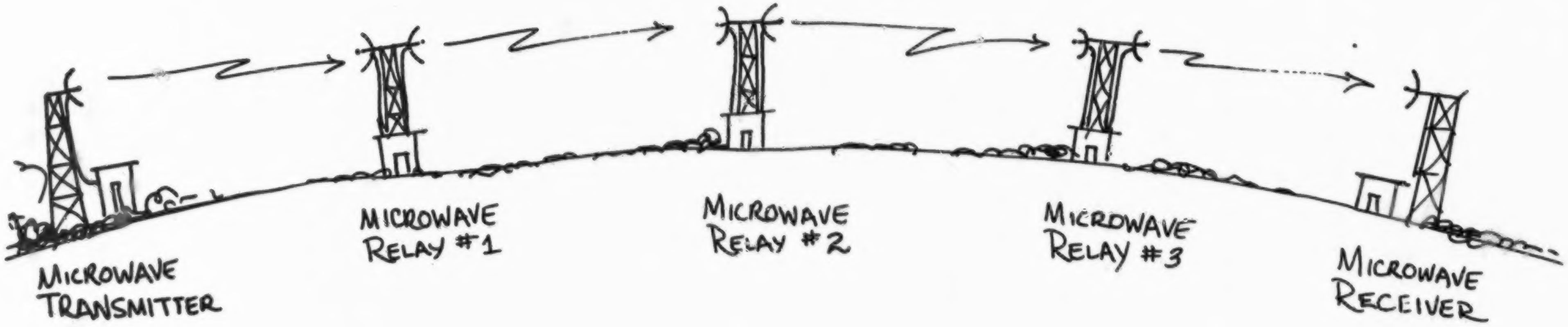

MICROWAVE TRANSMITTER
MICROWAVE RELAY #1
MICROWAVE RELAY #2
MICROWAVE RELAY #3
MICROWAVE RECEIVER

FIGURE 14

Company's TD-2 microwave system, which involves a large number of hops), heterodyne type of relay equipment is employed.

The essential difference between the back-to-back and heterodyne relay is that all unnecessary processing of the television signal is eliminated by converting, or translating, the frequency of the weak incoming signal before amplification to a higher power level and retransmitting. The more elementary back-to-back equipment employs the same type of equipment located at the terminals of the system and uses demodulators connected directly to modulators. This introduces unnecessary signal handling and, hence, signal degradation.

Point-to-point microwave systems utilize the frequency modulation (FM) method of imposing the video signals on the microwave carrier. This utilization takes advantage of the superior transmission properties of this system when coupled with the availability of spectrum space greater than 6 MHz per channel. The program sound channels are usually transmitted on the same carrier by a multiplexing technique, which uses a subcarrier, to permit the separation of the video and audio at the receiving end of the relay system.

The following frequency ranges and radio frequency (RF) bandwidths are available for non-common carrier television use:

Band A -- Ten channels, each 17 MHz wide, between 1900 MHz and 2110 MHz (not continuous)

Band B -- Ten channels, each 25 MHz wide, between 6875 MHz and 7025 MHz

Band C -- Twenty-two channels, each 25 MHz wide, between 12,700 MHz and 13,250 MHz

Additional microwave channel assignments in the bands 17,700 MHz-19,300 MHz, 19,400 MHz-19,700 MHz, 27,525 MHz-31,300 MHz and 38,600 MHz-

40,000 MHz are available on a case-to-case basis. Channel bandwidth and carrier frequency stability tolerances are to be specified in the individual authorizations. Microwave equipment for television purposes operating above 17,000 MHz is not available commercially at this writing.

DISPLAY OF TELEVISION IMAGES

The last link in the complete television system chain is the display of the reproduced images and accompanying sound at the final destination point, or points. The fidelity with which the original images and sound are reproduced in the display devices depends on the picture and sound fidelity of the entire system.

Television display devices may be classified as: direct view devices (video monitors and RF monitors or receivers) and projection systems (Schmidt optics projectors and the Eidophor projector).

Direct View Devices

The most important element in the television direct-view display device is the cathode-ray picture tube. The essential components of a cathode-ray tube (CRT), illustrated in Figure 15, are a large glass envelope having a short neck to house the source of electrons and a beam-forming assembly known as an electron gun. Magnetic deflecting coils are placed around the neck of the tube to deflect the electron beam in a systematic manner to produce the scanning pattern. The scanning electron beam is projected toward the large flat end of the tube which becomes the image viewing surface. The inside of this flat viewing surface is coated with a material called a phosphor which glows or emits light when the electron beam strikes it. If the electron beam is undeflected, the beam will strike the center of the face plate and produce only a pin-point of light. If the beam is deflected rapidly from side to side and downward to produce

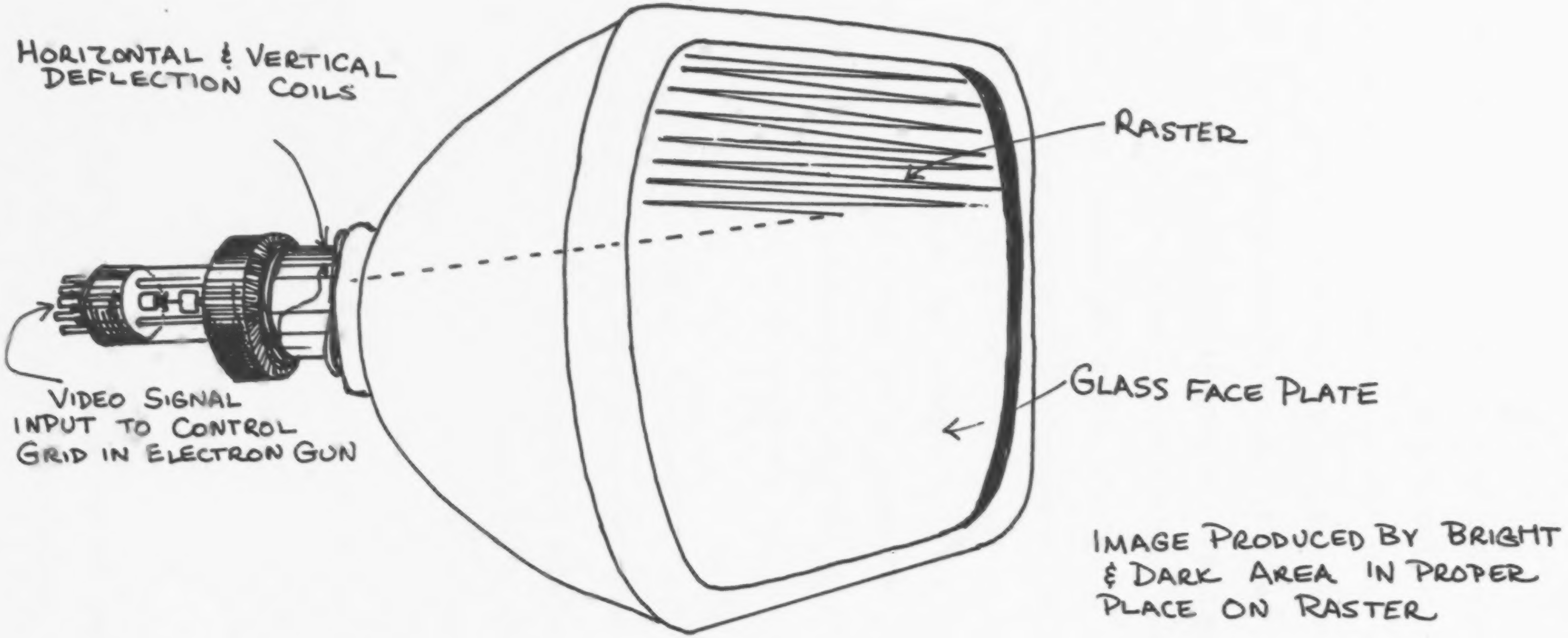

HORIZONTAL & VERTICAL DEFLECTION COILS
RASTER
VIDEO SIGNAL INPUT TO CONTROL GRID IN ELECTRON GUN
GLASS FACE PLATE
IMAGE PRODUCED BY BRIGHT & DARK AREA IN PROPER PLACE ON RASTER

FIGURE 15

the desired scanning pattern, the eye is deceived into seeing a uniformly illuminated rectangular area of light called a "raster." If the intensity of the beam is controlled, or modulated, by the received video signal by applying the video signal to the appropriate element of the electron gun (the control grid input), the raster will exhibit bright and dark areas across the face plate. Further, if the scanning pattern of the electron beam is identical to the scanning pattern emitted by the television camera tube (that is, in lock-step or synchronization), the bright and dark areas will appear in the correct geometric position to produce an image which is a replica of the scene before the distant camera. Thus, the electron beam literally "paints" a complete light image 30 times each second. The complete package consisting of the picture CRT, video amplifiers, focus, brightness and other controls, power supply and enclosure constitute the complete video monitor. The sound reproducer is usually a separate audio amplifier and speaker.

The RF monitor, or television receiver, is virtually identical to the video monitor except that it has a radio tuner equipped with a channel selector knob so that the video signal can be delivered to the display CRT from a selection of broadcast stations operating in the area. The RF monitor is usually provided with an integral sound reproducing (amplifier and speaker) facility.

Video monitors rather than RF monitors are generally used in television studios and in conjunction with a video closed-circuit coaxial cable distribution system.

Projection Systems

Quite often, the viewing group may be sufficiently large that a television picture considerably larger than the 27-inch size is desirable.

Under such circumstances, a projection system capable of providing a television image comparable in size and brightness to that obtained with a 16mm motion picture projector is required.

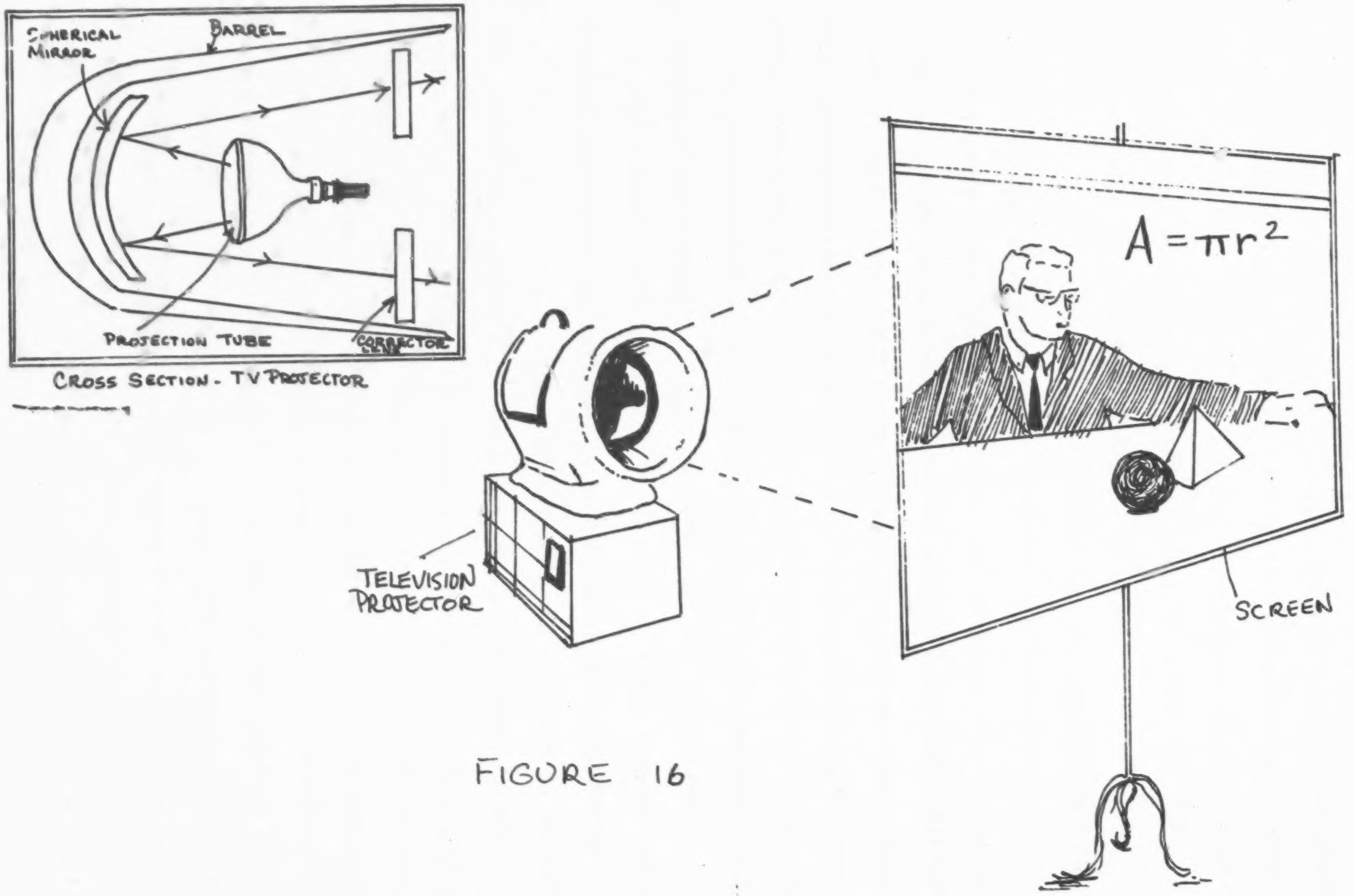
The most common and inexpensive type of television picture projection system is the Schmidt optical system in combination with a smaller (5") high-intensity CRT, as shown in Figure 16.

A very high-intensity television image appears on the face of the projection tube in exactly the same manner as the larger television monitor. The Schmidt optical system (the spherical mirror and the correcting lens) reverses the direction of the light rays to form the projected image on the screen. The barrel serves to provide mechanical support for the projection tube and lens system as well as protection against soft X rays emanating from the front of the projection tube face.

Projectors of this type throw an image on a standard motion-picture screen ranging from 6' X 8' to 20' X 15'. The screen is placed from 15 to 35 feet away from the projector. Either front or rear screen projection may be used with the appropriate screen.

The brilliancy of the projected image is considerably less than a typical 16mm motion picture (particularly for the larger 20' X 15' image) since the total light available for projection is limited by the maximum brilliancy of the image on the face of the television projection tube. The problem of low image brightness is usually minimized by locating the screen in a dark area to minimize the contrast-reducing effects of the ambient light striking the screen.

Notwithstanding the problem of low brilliancy -- and sometimes poor picture detail -- the Schmidt optics projector provides reasonably good overall results at a comparatively low cost of about $3,600.


SPHERICAL MIRROR
BARREL
PROJECTION TUBE
CORRECTOR LENS
TELEVISION PROJECTOR
$A = \pi r^2$
SCREEN

CROSS SECTION - TV PROJECTOR

FIGURE 16

There is general agreement among authorities that any television projection system capable of providing a large image of adequate brightness must be equipped with a high-intensity incandescent or gas-filled electric light source. Clearly, the use of a constant high-intensity light source requires the use of a "light valve," or light modulator, to permit varying the intensity of the constant light source under the influence of the video signal.

The Eidophor television projector, developed in Switzerland, utilizes a xenon arc operating in a quartz glass envelope under a pressure of 20 atmospheres as a high-intensity light source and a unique light modulator using the "control-layer" process. The control-layer process of light intensity control, or modulation, was developed in 1939 by Dr. Fritz Fischer, Professor of Applied Physics of the Swiss Federal Institute of Technology in Zurich, Switzerland.

The control-layer light modulator consists of a concave mirror coated with a thin oil film (about .1mm in thickness) which "wrinkles" under the influence of a scanning electron beam which is in turn controlled by the video signal. As the oil surface wrinkles, its reflectivity varies, thus obtaining different intensities of the reflected light originating from the fixed high-intensity xenon light source. The electron beam assembly is identical to that used in a direct-view monitor and is enclosed in a vacuum chamber with the oil-coated concave mirror.

The fundamental elements of an Eidophor projector and how they are related are illustrated in Figure 17. A photograph of the projector is shown in Figure 18.

The Eidophor is regarded as a television projector which provides by far the brightest television image possible with the lowest geometric

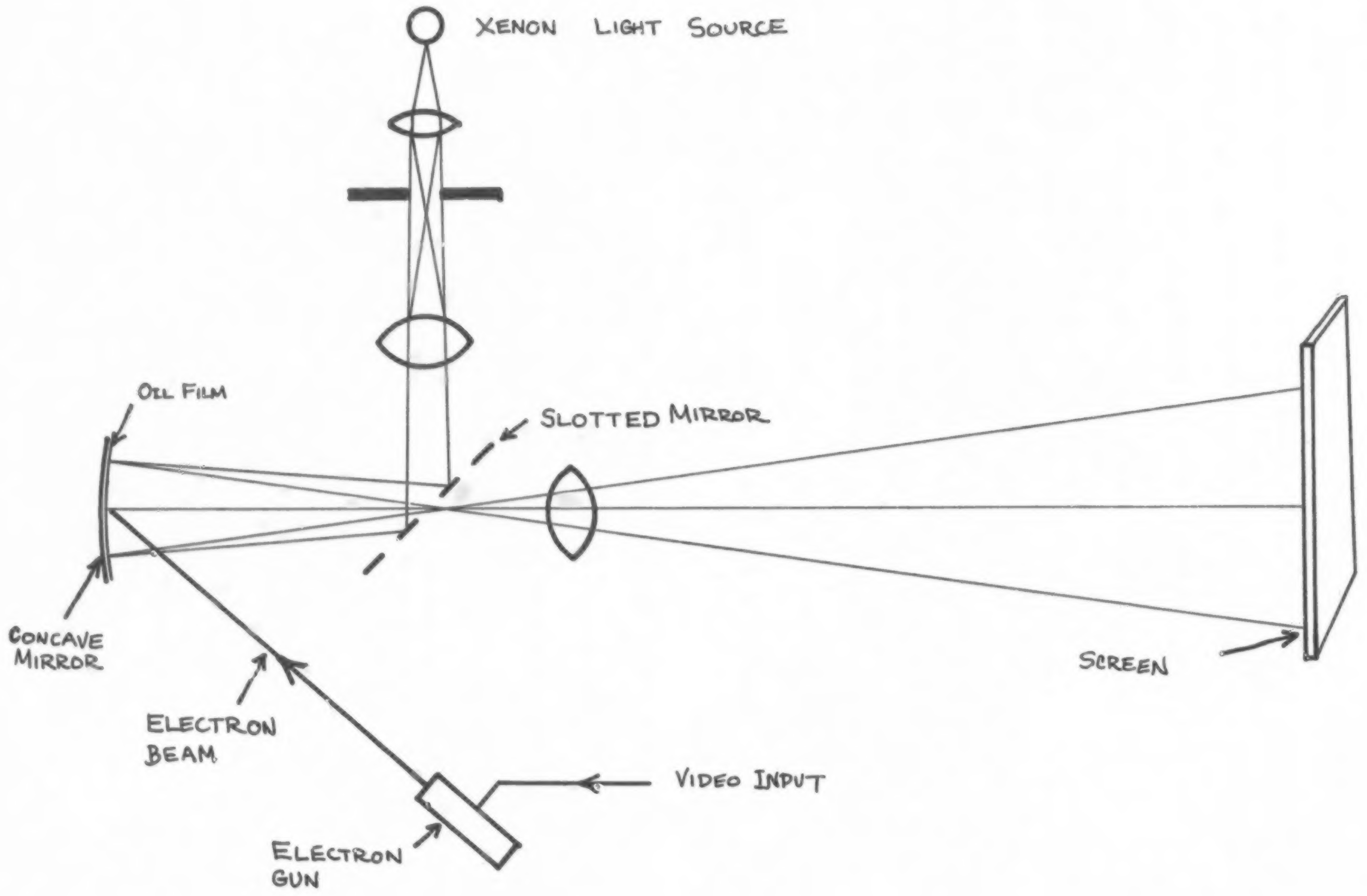

XENON LIGHT SOURCE
OIL FILM
SLOTTED MIRROR
CONCAVE MIRROR
SCREEN
ELECTRON BEAM
VIDEO INPUT
ELECTRON GUN

FIGURE 17

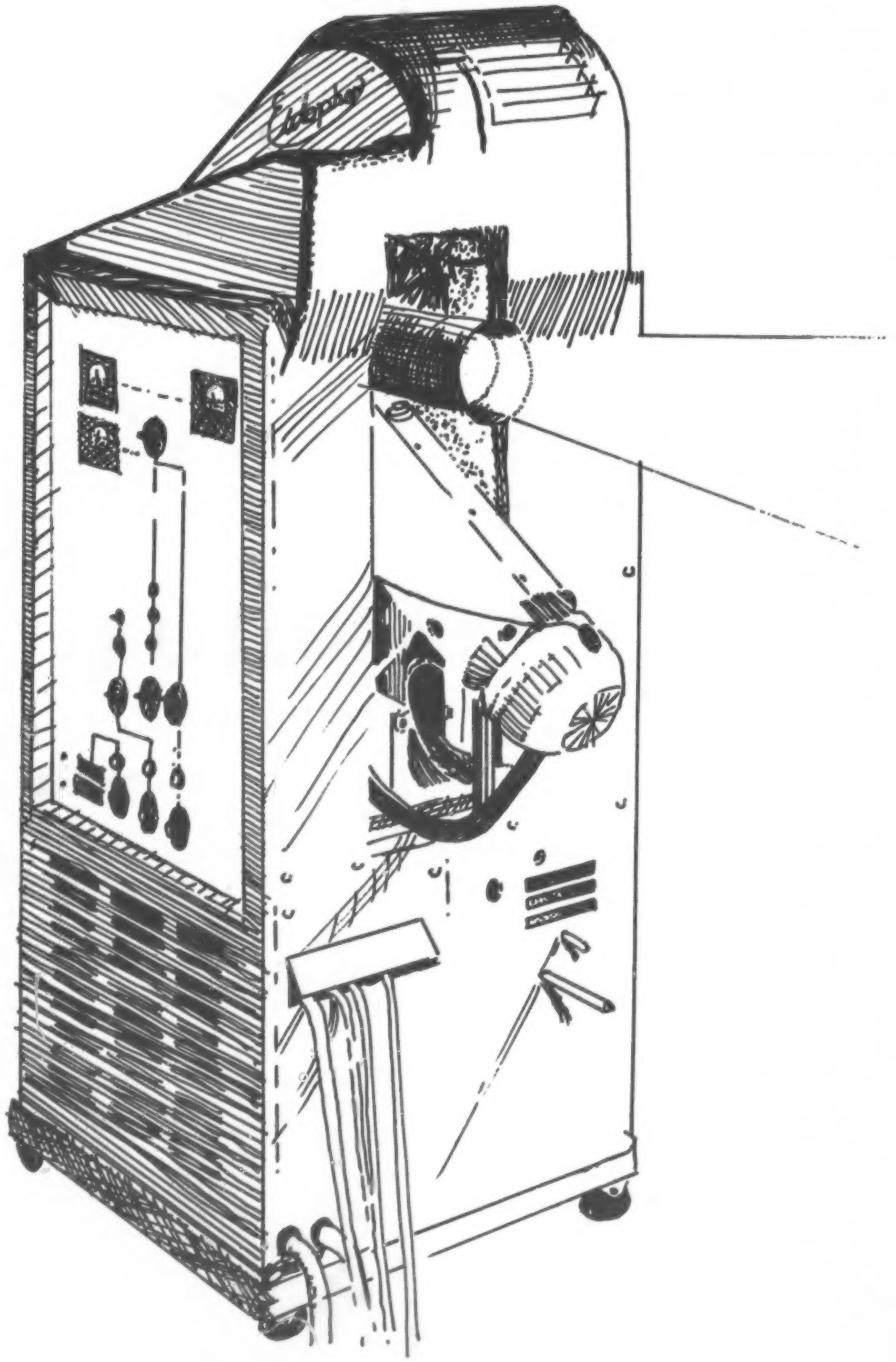


FIGURE 18

distortion. However, the Eidophor is relatively expensive, costing in the neighborhood of $50,000, but it is the only known device which projects television images equal to that obtainable with a good motion picture projector.

THE RECORDING AND REPRODUCTION OF TELEVISION IMAGES AND SIGNALS

The known methods of recording television programs for delayed broadcast or use fall into three general categories: 1) photographic recording and reproduction of images, 2) direct recording and reproduction of video signals, and 3) electron beam recording and reproduction.

Photographic Recording and Reproduction

Two different photographic techniques are available. The first method involves the direct motion-picture photography of the scene with a 16mm (or 35mm) movie camera instead of a studio television camera. Playback of a delayed television broadcast or closed-circuit transmission is accomplished by a 16mm motion picture projector coupled with a television camera system, which is known as a "film chain." The film-chain camera is usually equipped with a fixed optical or moving mirror device which permits the film camera to be used with multiple film sources (such as another 16mm movie projector or a 2" X 2" slide projector) on a time shared basis. This device is known as an optical multiplexer. A film-chain with multiple inputs is shown in Figure 19.

The 16mm motion picture projector used for television playback must be equipped with a special shutter mechanism and exposure sequence (called a 2:3 pulldown) which equalizes the differences between the 24 frames per second motion picture standard and the 30 frames per second television standard. In this way, the almost limitless supply of standard motion picture film is made available for television use.

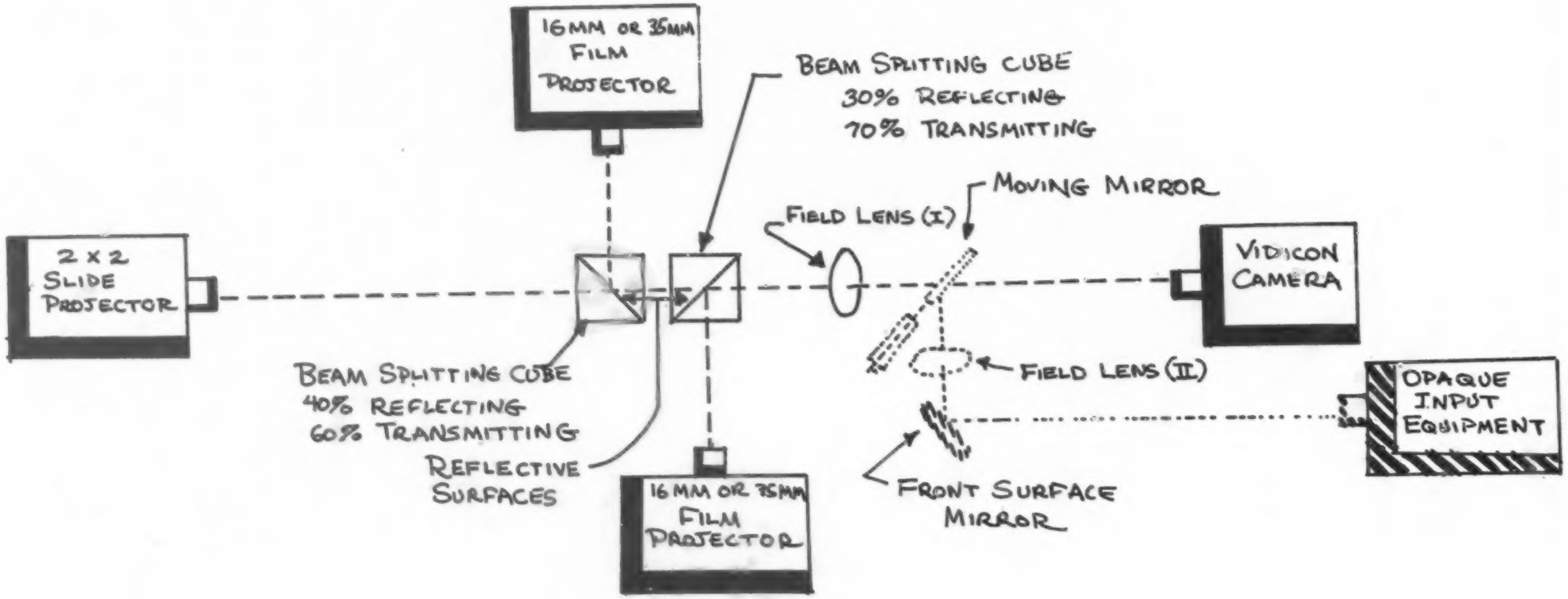

16MM OR 35MM
FILM
PROJECTOR
BEAM SPLITTING CUBE
30% REFLECTING
70% TRANSMITTING
MOVING MIRROR
FIELD LENS (I)
2 X 2
SLIDE
PROJECTOR
VIDICON
CAMERA
FIELD LENS (II)
OPAQUE
INPUT
EQUIPMENT
BEAM SPLITTING CUBE
40% REFLECTING
60% TRANSMITTING
REFLECTIVE
SURFACES
16 MM OR 35MM
FILM
PROJECTOR
FRONT SURFACE
MIRROR

FIGURE 19

The second -- and more common -- photographic method involves placing the recording camera in front of a television monitor so that the electronically displayed images may be recorded on 16mm film. In this way no photographic editing is necessary and all the special effects unique to television can be utilized. This method is known as "kinescoping" and the film product is called a kinescope. The kinescope recording/reproducing technique was widely used before the almost universal use of magnetic tape video recording and is familiar to anyone who has watched commercial television in its early days.

The quality of kinescope recordings has improved considerably over the low-detail, washed-out pictures characteristic of the early days due largely to improved exposure and photographic process controls. Kinescope techniques are still utilized for the purpose of making 16mm movies of video tape recordings for showing on ordinary film projectors.

The accompanying program sound is usually recorded optically along a track adjacent to the sprocket holes. Both single and double systems are in general use. In the single system the sound is recorded simultaneously with the picture; in the double system, the sound is recorded separately and combined with the picture later.

One of the significant improvements in photographic recording/reproducing techniques is the recording of sound on a magnetic stripe placed on the film in place of the optical track.

Direct Video Signal Recording

Perhaps the most modern approach to the recording and reproduction of television images is the magnetic tape process in which the image, or light, step is completely circumvented. In this way, the inevitable

8

degradation in the tonal shades of the reproduced picture, due to variations in the photographic process, is eliminated, and the recording is available for immediate reproduction -- a tremendously valuable bonus. In the magnetic tape process, the video signal, which corresponds to the picture elements, is used to influence directly the positions of the magnetic coating on the tape backing. The process is quite similar to audio-magnetic tape recording except that changes must be made to extend the frequency response to record television signals adequately without excessive degradation.

The frequency response, or bandwidth, attainable with most recording/reproducing techniques -- particularly magnetic tape techniques -- is determined largely by the ratio of the medium velocity (in this case the velocity of the magnetic tape) to the playback head gap width, as shown in Figure 20. With the narrowest gap width available, the required medium velocity is so great as to be impractical for television use. In the modern video tape recorder/reproducer this problem is solved by moving the head at high speeds across the tape surface and moving the tape just fast enough to separate the tracks.

Two different types of video recorder/reproducers are in general use: transverse scan (also known as quadruplex) machines and helical scan machines.

Transverse scan machines use magnetic tape two inches wide and the magnetic tracks are placed on the tape along the two inch dimension, or transverse to the direction of tape motion. A rotating head wheel is used in which four identical heads are imbedded into the edge of the wheel exactly 90° apart. The magnetic tape is moved in a direction

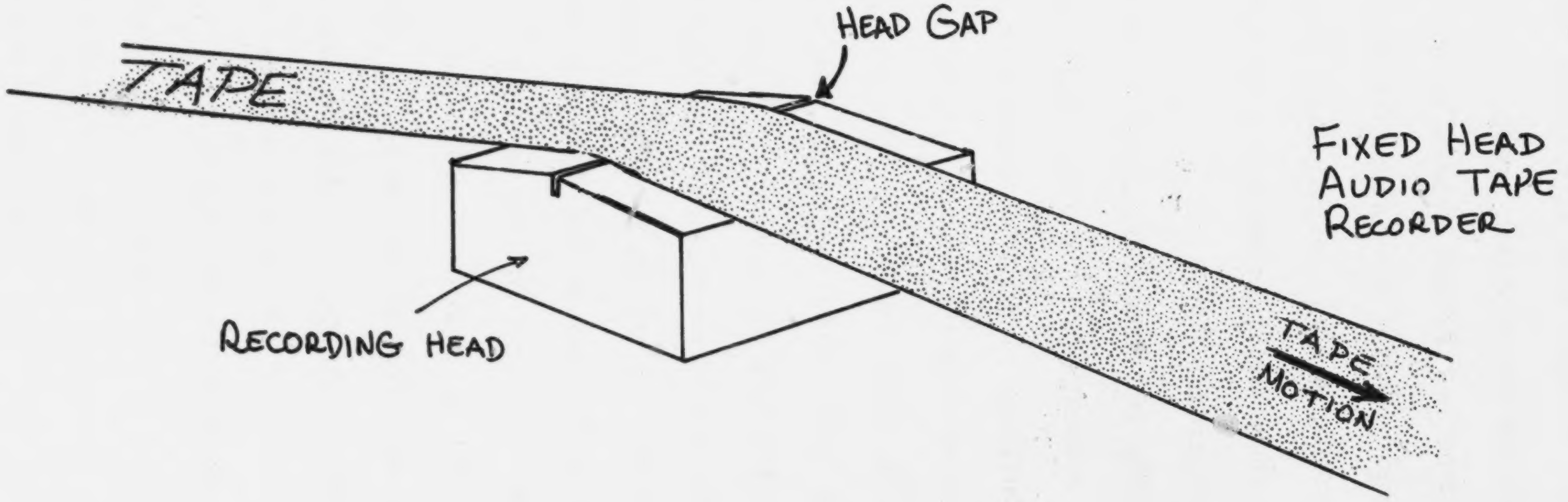

Head Gap
Tape
Fixed Head
Audio Tape
Recorder
Recording Head
Tape
Motion

Figure 20

perpendicular to the imbedded head motion when the head wheel rotates just fast enough to separate the adjacent tracks. As illustrated in Figure 21, a continuous recording is achieved because as one imbedded head loses contact with the magnetic coating the adjacent head moves into position to lay an adjacent recorded track. In this way a high enough medium-velocity to gap-width ratio is achieved to provide a bandwidth wide enough for satisfactory reproduction.

The program audio is recorded longitudinally along one edge of the tape by means of a conventional stationary audio head.

The modern quadruplex video tape recorder is a scientific marvel of mechanical precision and sophisticated electronics. To provide satisfactory operation, the heads imbedded in the head wheel panel must be switched out as they leave contact with the tape and the adjacent head switched in as it moves into position to take its place. Further, during the playback process, the heads must scan the same tracks made during recording. This requirement means that the rotational speed of the head wheel and the speed of the tape motion during reproduction must be identical to a very small tolerance to that used during recording. Elaborate servomechanisms to hold the head wheel motor and the tape transport capstan-drive motor under control and constant speed are required. A control track is recorded on the tape in much the same manner as the program sound to provide a reference for the electromagnetic servomechanisms.

Successful operation of the quadruplex video tape recorder/reproducer involves the application of many sophisticated electronic techniques which cannot be adequately treated in this short presentation.

A large family of lower cost -- and also lower performance -- video tape recorders have become available during the last few years. These

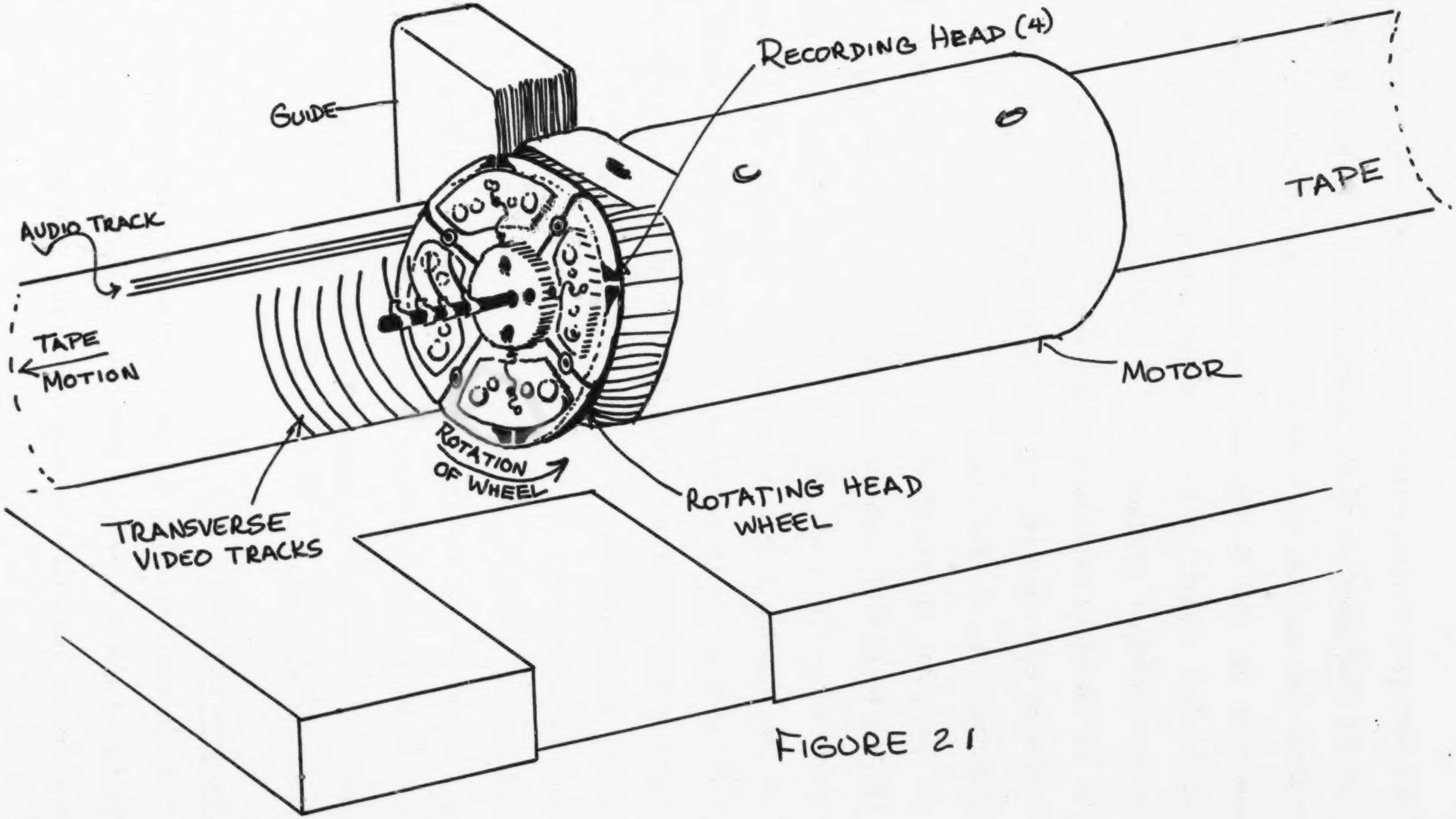

GUIDE
RECORDING HEAD (4)
TAPE
AUDIO TRACK
TAPE MOTION
MOTOR
ROTATION OF WHEEL
ROTATING HEAD WHEEL
TRANSVERSE VIDEO TRACKS

FIGURE 21

machines have been labeled helical scan, or "slant-track," machines because of the configuration of the magnetic track, as shown in Figure 22. The helical scan machines of different makes (and sometimes even different models by the same manufacturer) use either one or two heads and either one- or two-inch magnetized tape. The net result is that no two machines sold by two different manufacturers are compatible in that a recording made on one cannot be reproduced on the other. Needless to say, video tapes recorded on transverse machines (quadruplex) cannot be reproduced on helical machines or vice versa.

The important characteristics of helical scan machines are: lower cost ($1,500 to $8,000), reduced size and weight and, unfortunately, lower performance standards. There is a fond hope among existing users of video tape recorders that the performance standards will be improved eventually without significantly sacrificing cost, size and weight and that a common manufacturing standard will be adopted so that recordings made on any one machine can be reproduced on any other.

When that time comes, or perhaps even before, there is little doubt that helical scan machines will eventually find a permanent niche in television. At the present writing, helical scan machines cannot be used for VHF/UHF broadcast purposes without the use of an elaborate video processing amplifier to reshape the synchronizing signal adequately to meet current FCC broadcast standards.

Electron Beam Recording

Electron beam recording and reproduction of television images is a combination of the photographic technique (optical) and the direct video signal technique (magnetic) already described. Electron beam recording

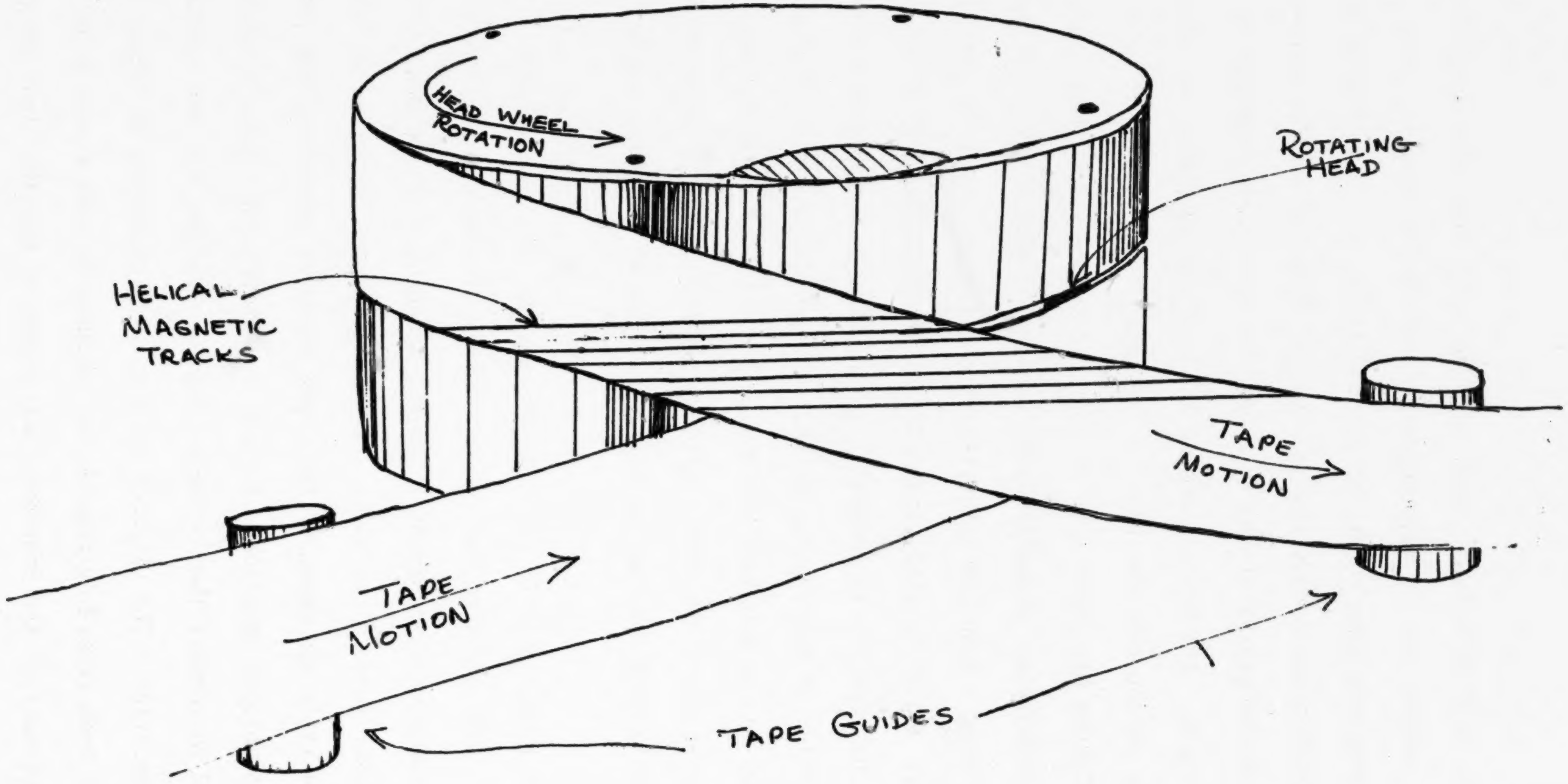

HEAD WHEEL ROTATION
ROTATING HEAD
HELICAL MAGNETIC TRACKS
TAPE MOTION
TAPE MOTION
TAPE GUIDES

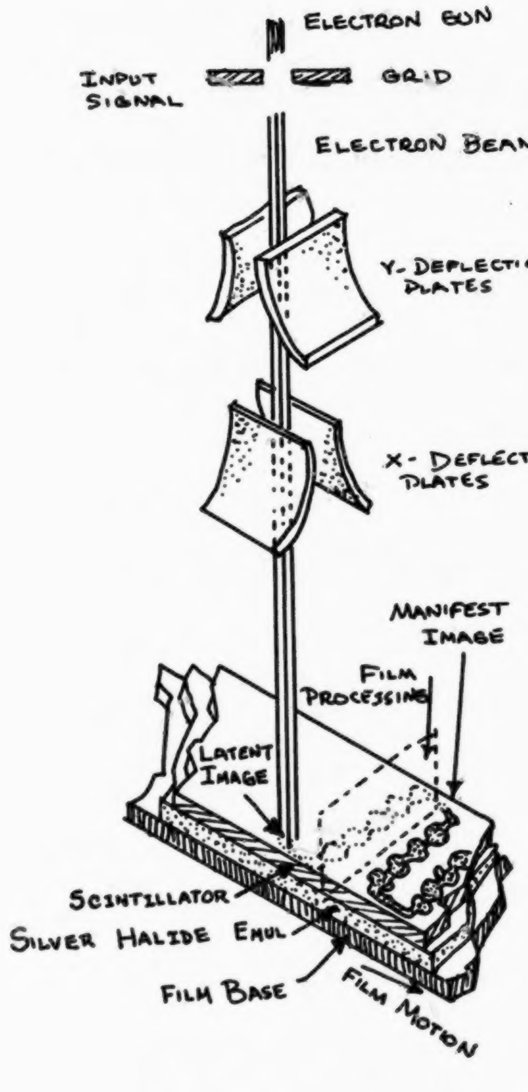
FIGURE 22

is a combination of well-known techniques used for some time in electron microscopes, cathode ray oscilloscopes and television picture tubes.

In the electron beam recording process (EBR), shown in Figure 23, a focused electron beam is directed at a moving film and scanned across the film by deflection plates of the type used in television camera pickup and display tubes. The information to be recorded modulates, or varies, the intensity of the electron beam in precisely the same manner as in a television picture display tube. In addition to the usual photo-sensitive silver halide emulsion, a scintillator coating is placed over the light-sensitive coating. When the scintillator coating is struck by the electron beam, it glows and emits light proportional to the intensity of the electron beam. This process is identical to the action of the phosphorus coating on the inside of the viewing surface of a television picture display tube described in the previous section. The light generated by the scintillator exposes the photographic film to produce a latent image which can be processed like ordinary photographic film to provide a permanent copy.

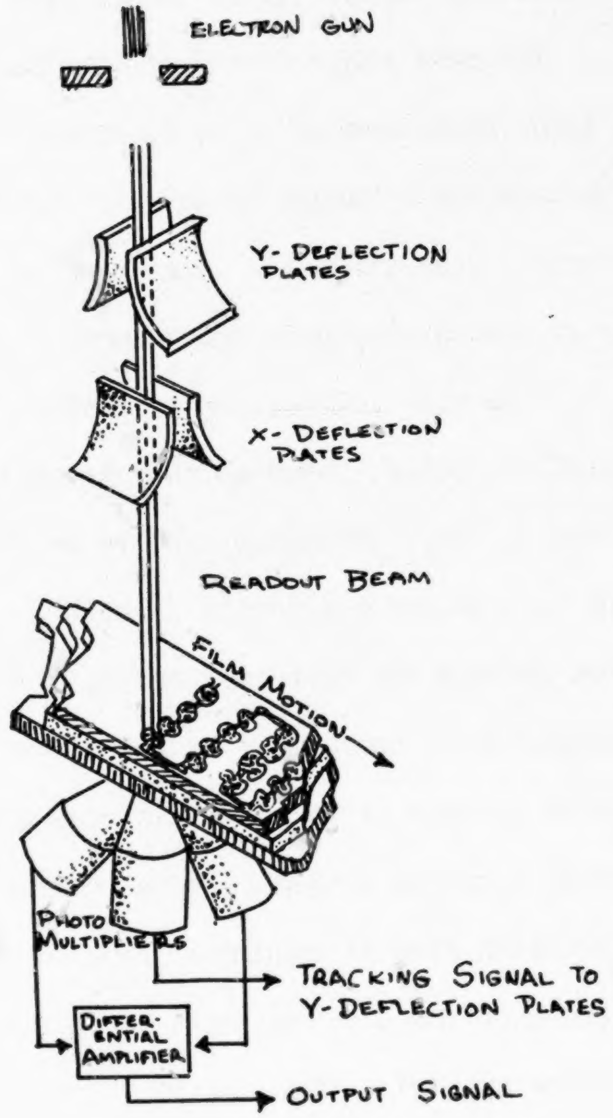
Playback is achieved by scanning the moving film surface with a constant-intensity electron beam in a running pattern identical to that used during the recording process. As the scanning electron beam strikes the scintillator surface, it emits light which passes through the film surface where it is modulated by the light and dark pattern of the photographically developed emulsion. A photo sensitive cell (photo-multiplier tube) is used to convert the impinging light variation into the original electrical variation. The playback process is illustrated in Figure 24.

Electron beam recording/reproducing techniques have a very promising future free of many of the inherent limitations of magnetic tape recording,


ELECTRON GUN
INPUT SIGNAL
GRID
ELECTRON BEAM
Y- DEFLECTION PLATES
X- DEFLECTION PLATES
MANIFEST IMAGE
FILM PROCESSING
LATENT IMAGE
SCINTILLATOR
SILVER HALIDE EMUL
FILM BASE
FILM MOTION

RECORD

FIGURE 23


ELECTRON GUN
Y- DEFLECTION PLATES
X- DEFLECTION PLATES
READOUT BEAM
FILM MOTION
PHOTO MULTIPLIERS
TRACKING SIGNAL TO Y-DEFLECTION PLATES
DIFFER-ENTIAL AMPLIFIER
OUTPUT SIGNAL

PLAYBACK

FIGURE 24

even though a four-minute processing interval is required before playback is possible.

Although conventional video tape recording techniques are limited to a bandwidth capability of 10 MHz, EBR is capable of achieving up to 100 MHz.

The next stage of the EBR system development might involve the use of a laser beam instead of an electron beam. This variation would eliminate the need for a vacuum system and the scintillating surface demanded by the electron beam since the laser beam is capable of exposing the film directly in an open atmospheric environment.

Some very interesting properties are exhibited by another variation of the EBR process, known as the thermoplastic tape recording and reproduction process. This technique employs an electron beam "writing stylus," as in the EBR process previously described. However, as the scanning electron beam strikes the uniformly moving film (usually standard 16mm size) the thermoplastic coating is heated almost instantaneously to produce an embossed surface of varying thickness and hence optical transparency. Although a vacuum system is required for the electron beam, no photographic processing step is required prior to playback. Furthermore, if the scanning pattern of the electron beam is chosen to match the scanning pattern in the picture tube of a standard television receiver, the individual embossed picture frames can be recorded on 16mm film, which would produce images visually identical to the individual frames on standard motion picture film. As a consequence, a thermoplastic EBR recording could be used either to reproduce a high-fidelity video signal (EBR type of playback with electron beam sensing) or projected onto a screen with a 16mm movie projector as if it were ordinary movie film!

A practical form of Electron Beam Recording has been announced recently by CBS Laboratories. This video recording/reproduction process, labeled Electron Video Recording, or EVR, has the potential for revolutionizing the recording and reproduction of television programs. The chief virtue of the EVR process is the low cost of making multiple copies for professional or home reproduction. Thus, EVR video recordings may become as commonplace as Long Playing phonograph records. Interestingly enough, the EVR process was developed under the direction of Dr. Peter C. Goldmark of CBS Laboratories, the developer of the Long-Playing phonograph record. The recording process, however, will require elaborate and expensive equipment. It is, thus, unlikely that low-cost video recorders using the EVR process will become available for other than professional use in the near future.

APPENDIX A

GLOSSARY OF TERMS

AMPLIFIER - An electronic component which receives a weak signal from any original sound or visual source (microphone, record player, tape-head, or television camera) and strengthens it to the point where it can drive a speaker or reproduce a picture on a television screen. While audio and video amplifiers are designed differently according to their respective function, the basic principle of a good amplifier is that it does not change (i.e., distort) the original signal in any way other than to give it the necessary boost along the way.

ANTENNA - A device for receiving and then conducting radio and/or television signals that have been transmitted through space. In television the simplest form of antenna is the familiar "rabbit ears" placed atop the receiver. An extension of this type is the roof antenna which can service up to four sets, depending upon the strength of the signal received and the distance of the sets from the antenna. For optimum quality and consistency of reception, the antenna is connected to a master distribution system with electronic amplification for all available broadcast channels.

AUDIO - Refers to the sound portion and the related equipment of any communications system. Depending upon the type of television system in use, audio may be transmitted either over the same signal carrier with the television impulses or may be a completely independent system.

AUDIO-VIDEO MIXER (MODULATOR) - An electronic component of an RF (radio frequency) transmission system that combines (or modulates) the separate audio and video signals from microphones and camera respectively into a single high frequency signal for transmission to the receiving equipment where the signals are again separated and directed to the speaker and screen.

BAND - A portion of the frequencies in the spectrum allocated by the FCC for specific purposes. For example, AM radio extends from 550-1600 kilocycles, VHF (very high frequency) television from 54-88 and from 174-218 megacycles for channels 2-6 and 7-13 respectively, FM radio from 88-108 megacycles, UHF (ultra high frequency) television from 470-890 megacycles (channels 14-83). A new educational television band of 2500-2690 megacycles was allocated in 1963 for point-to-point microwave transmission.

BANDWIDTH - The frequency range of a specific signal being transmitted. Each broadcast television channel in the United States covers 6 megacycles for both audio and video. For example, channel 2 covers a bandwidth extending from 54-60 megacycles.

BROADCAST - The open circuit transmission of either radio or television signals through the air at frequencies which can be received by any appropriately tunable equipment within range of the transmitter. All broadcasting is regulated by the Federal Communications Commission.

CAMERA - In television that device which, by utilizing an optical system, a light-sensitive electronic tube and an electronic scanning device, converts a visual image into electrical impulses.

CAMERA CHAIN - One or more cameras with such associated electronic devices as needed to transmit a television picture.

CARRIER - The electronic wave by which audio and video impulses are carried from transmitter to receiver.

CARRIER FREQUENCY - The number of complete cycles per second (frequency) of a carrier wave.

CATHODE-RAY TUBE (CRT) - An electron tube in which a beam of electrons from a heated element, the cathode, is used to reproduce an image on the fluorescent face of the tube.

CHANNEL - The segment of the broadcast spectrum to which a television station is assigned or to which a closed-circuit television camera is tuned when transmitting via radio frequencies. The actual channels used in any closed-circuit installation would normally be those not allocated to a local broadcast station.

CLOSED CIRCUIT (CCTV) - A system of transmitting television signals to receiving equipment that is directly linked to the originating equipment by coaxial cable, microwave relay or telephone lines.

COAXIAL CABLE (CONCENTRIC LINE) - A transmission line formed by two coaxial conductors, each insulated from the other by some suitable dielectric material such as air or polyethylene, polyfoam, teflon, etc.

COMPATIBLE COLOR SYSTEM - A color television system which permits normal black and white reception of its transmitted signals without altering currently used receivers.

CONTRAST - The relation of black to white on a receiver or projection screen.

CONVERTER - In television an electronic device that converts broadcast signals from one frequency range to another. A VHF receiver with a converter can receive UHF channels. Or a master antenna and distribution system so equipped can service any number of standard VHF receivers with programs initially telecast and received on UHF frequencies, then converted to permit reception on any VHF channel not being used in the particular area.

DEMODULATION - The process of removing the video and audio signals from their respective carrier waves.

DIRECT CURRENT - Electric current which flows through a circuit in only one direction.

DIRECT-VIEW RECEIVER - A television set arranged so that the formed image is viewed directly on the face of the picture tube.

DIRECTIONAL ANTENNA - An antenna radiating or receiving radio waves more effectively in some directions than in others.

EDUCATIONAL TELEVISION STATION - A non-profit television station operating to serve community needs in the areas of instruction, cultural development, etc.

FADING - 1) Variation in the intensity of a received radio signal, generally caused by changes in transmission paths. 2) Electronically weakening a television picture until the screen goes to black.

FCC - Federal Communications Commission.

FIDELITY - The exactness with which a radio or television system reproduces sound or picture signals.

FILM CHAIN - An equipment arrangement with a television camera focused on a multiplexer into which an assortment of projectors (2" X 2" slide, 16mm motion picture, opaque) have been directed from different angles. Electrical circuits make it possible to switch into the system selected images from any of the projectors in turn. More than a single film chain can be installed, especially if central distribution of visuals by closed circuit is contemplated in an institution. All television stations have at least one of these chains.

FRAME - A single complete television or motion picture scene in a ratio of 3 units high and 4 units wide. Thirty frames per second are shown on a television screen; twenty-four frames per second are generally used in motion pictures. Each television frame has 525 lines.

FRAME FREQUENCY - The number of times per second a television picture area is completely scanned (30 times a second).

FREQUENCY - The number of cycles completed each second by an electric current or a sound wave.

FREQUENCY MODULATION (FM) - A method of modulation in which the frequency of the carrier wave is varied while the strength (amplitude) of the carrier wave remains constant. FM is the standard method of transmission and reception of the sound in television.

IMAGE ORTHICON - A television camera tube so sensitive it can televise (in black and white) any scene the eye can see, even under low lighting conditions; more expensive than vidicon, used for professional studio broadcasting; requires expert handling.

INTERFERENCE - Disturbance in radio reception caused by undesirable signals or stray currents from electrical, atmospheric conditions, static, etc.

INTERLACE - The process of scanning alternate lines of a television picture to reduce flicker.

ITFS - Instructional Television Fixed Service, which operates in the 2500-2690 MHz band.

KILOWATT (KW) - A unit of electrical power equal to 1,000 watts.

KINESCOPE - A film recording made by a 16mm motion picture camera especially designed to photograph a television program directly off the front of a television tube. The sound portion of the program is also recorded simultaneously. The film so produced can then be shown on any 16mm projector, as well as on television.

MASTER DISTRIBUTION SYSTEM - Comprises antenna and amplifiers for boosting over-the-air signals, plus cables and tap-off connections for use of cameras and receivers throughout a building.

MEGACYCLE - 1,000,000 cycles (1 MHz) per second, used as a unit of measurement of frequency. 1,000 kilocycles is equal to one megacycle.

MICRO - A prefix meaning one millionth, as "microvolt."

MICROWAVE - A method of transmitting closed-circuit radio and television signals through the air on a highly directional line-of-sight system from the originating station to one or more receiving stations. Although a private system, microwave transmission is regulated by the FCC.

MICROWAVE RELAY - A series of low-power, high-frequency transmitters and receivers strategically spaced and located to permit radio or television contact between widely separated points.

MODULATION - The process of impressing audio or video impulses on the carrier wave for transmission through the air.

MONITOR - A special type of high quality television receiver used specifically in video transmission, rather than RF. Video monitors are not tunable to channels and must be used with video cameras. They normally have no provision for sound reception. (The term "monitor" is also used informally to designate any receiver being used by the cameraman or program director to check the picture being sent out.)

MONOCHROME TRANSMISSION - The transmission of television signals which can be reproduced in graduations of a single color only (black and white).

MPATI - Midwest Program on Airborne Television Instruction.

MULTIPLEXER - In television a specialized optical device that makes it possible to use a single television camera in conjunction with one or more motion picture projectors and/or slide projectors in a film chain. The camera and projectors are in a fixed relationship, and prisms or special (dichroic) mirrors are used to provide smooth and instantaneous non-mechanical transition from one program source to the other.

NETWORK - A group of television stations connected by radio relays or coaxial cable so that all stations may simultaneously broadcast a program. "Tape networks" bicycle tapes between the stations.

OSCILLOSCOPE - A test instrument that indicates voltage and current characteristics on a screen similar to that of a television receiver.

PICTURE TUBE - The television cathode-ray tube used to produce an image by variation of the beam intensity as the beam scans the raster.

PROJECTION RECEIVER - A television set with a small but high-intensity picture tube. The tube in this instance operates through an optical system to project images which are viewed on a screen. Although the images are not so bright as those achieved with direct-view receivers, relatively large projections can be achieved.

PROJECTION TELEVISION - A combination of lenses and mirrors which projects an enlarged television picture on a screen.

RADIO - Communication through space by means of electromagnetic waves for transmission and reception of messages, sounds, photographs and pictures in motion without the use of connecting wires.

RADIO CHANNEL - A band of frequencies allotted by the FCC to each station for radio, communication and broadcasting purposes. At present, the width of standard television channels is 6 megacycles; FM, 200 kilocycles; and standard radio broadcast channels, 10 kilocycles.

RADIO RELAY - A station which automatically relays, or retransmits, television or sound programs.

RADIO WAVE - An electromagnetic wave produced by rapid reversals of current flow in a conductor known as the antenna, or aerial. Such a wave travels through space at the speed of light -- 186,000 miles per second.

RASTER - The pattern, or framework, of scanning lines that illuminates the cathode-ray screen when no television signal is being received.

REAR SCREEN - A system using a translucent screen through which an image is projected from the rear, usually from a 3 1/4" X 4 1/4" projector, to full-screen size. This image is then taken by the television camera. A live subject can appear before the rear screen, making it appear that the scene shown on the screen is a background for the person shown.

RECEIVER - Any television set; more specifically, one designed for tuned (radio frequency) channel reception of sound and picture. May be either a standard "home set" or one designed especially for classroom use.

RESOLUTION - The details that can be distinguished on the television screen. Vertical resolution refers to the scanning lines one sees on the screen. Horizontal resolution refers to the number of variations within each scanning line and is variable according to the bandwidth used. Broadcast (and RF closed circuit) television, limited to 4.5 megacycles bandwidth, has about 300 lines of horizontal resolution as seen on an RF receiver. With high resolution video cameras and monitors, operating on a 10 megacycle bandwidth, horizontal resolution can be as high as 800 lines.

SCANNING - The process of deflecting the electron beam in a camera or picture tube so that it moves at high speed from left to right in a sequence of rows or lines from top to bottom, thus changing light and shadows of a scene into electrical impulses to form the image of the receiver tube.

SERVICE AREA - The region surrounding a broadcasting station in which that station's signals can be received with satisfactory results.

SIGNAL - Information transposed into electrical impulses; two basic signals are involved in television transmission -- the picture or video signal and the sound or audio signal; each signal contains electrical impulses representing elements transmitted.

SPECTRUM - The entire range of electromagnetic radiations, from the longest known radio waves to the shortest known cosmic rays. Light, the visible portion of the spectrum, lies about midway between the two extremes.

SWITCHER - A control device which permits the selection of one image from any of several cameras. The image selected is then processed into the transmission equipment.

SYNCHRONIZING GENERATOR - An electronic device that synchronizes the image scanned by the camera with the image appearing on the receiving tube. It is also required to avoid "picture roll up" when switching between two or more cameras in a single program.

TELECAST - A broadcast of both sight and sound.

TELEVISION - The radio or electrical transmission of a succession of images and their reception in such a manner as to give a substantially continuous and simultaneous reproduction of an object or scene before the eyes of a distant observer.

TELEVISION BROADCAST SIGNAL - A combination of two radio frequency carriers spaced by 4.5 MHz, the lower one being amplitude-modulated by a standard composite picture signal, the upper one being frequency-modulated by the accompanying audio signal.

TELEVISION CHANNEL - A band of frequencies 6 megacycles wide in the television broadcast band and designated either by a number or by the extreme lower and upper frequencies.

TRANSMISSION LINE - A conductor system designed to transmit electrical impulses along a continuous path from one place to another.

UHF (ULTRA HIGH FREQUENCY) - Used to designate Channels 14 through 83, which operate in a frequency band of 470 to 890 megacycles.

VHF (VERY HIGH FREQUENCY) - Used to designate Channels 2 through 13 and FM, which operate in frequency bands of 54-72, 76-109 and 174-216 megacycles.

VIDEO - A system of transmitting television, utilizing bandwidth frequencies from zero to 15 megacycles to carry the picture signals. Only one video signal at a time can be transmitted over the cable. Normally, a separate audio cable must be used for sound, if required. Picture quality is superior to that of RF, but the range of transmission is comparatively short and requires more frequent line amplification.

VIDEOTAPE RECORDER (VTR) - A unit designed to electromagnetically record television program material for rebroadcast at any time. Tapes may be edited to improve content.

VIDICON - A television tube of moderate sensitivity, adequate for most educational broadcast requirements (black and white); much less expensive than image orthicon equipment; does not require highly expert handling.

FEDERAL COMMUNICATIONS COMMISSION

65629

WASHINGTON, D.C. 20554 March 29, 1965

INTRODUCTION TO INSTRUCTIONAL TV FIXED SERVICE

The "Instructional Television Fixed Service", which the Federal Communications Commission established in 1963, is proving to be a particular boon to education in its use of television as an instructional medium.

It furnishes a means for transmitting instructional material for school use on channels other than those used for regular noncommercial educational TV broadcasting. This is done on 31 channels in the 2500-2690 Megacycles band allocated for that purpose. A single central transmitter is able to serve a number of scattered local schools, where the transmissions are converted for classroom viewing on regular TV receivers.

The primary purpose of the new service is to send visual and accompanying aural instructional material to selected receiving locations in public and private schools, colleges and universities and other instructional centers for the formal education of students. Systems licensed for this purpose, however, may also be used for other purposes, among which are the transmission of cultural and orientation material to educational institutions; special training material to selected receiving locations outside the school system, such as hospitals, nursing homes, police and fire stations, training centers, clinics, rehabilitation centers, commercial and industrial establishments; professional material to groups or individuals to inform them of new developments and techniques in their fields and instruct them in their use; in-service education; and other related materials directly concerned with formal or informal instruction and training. When not being employed for such purposes, the facilities may be used for handling administrative traffic, such as the transmission of reports and assignments and conferences with personnel.

Of special significance to educators is that up to five* programs (the FCC has authorized a maximum of five channels to each licensee) may be transmitted and received simultaneously in any given educational institution, thus largely eliminating the major problem in previous educational utilization of television -- that of scheduling. Not only does this system permit a given school to receive several different instructional programs at the same time, but the system creates television pathways that are no longer available in many geographical areas because broadcast channels have all been assigned. This new service, then, is intended to supplement -- not replace -- the standard educational TV broadcast service.

Of special significance to administrators is the relatively low cost of ITFS (or 2500 mc/s) transmitting equipment compared to that of standard open-circuit broadcasting. However, while the 2500 mc/s signal is transmitted openly, the cost of a special receiving antenna and converter exceeds the cost of normal home receiving equipment and, for practical purposes, only those institutions specifically utilizing the signals would likely make the investment. Maintenance is low in cost and does not require specially trained personnel.

Stations in this service may additionally be used to relay educational material to and from commercial and noncommercial TV stations, but not to interconnect TV fixed systems in different areas or to establish relay systems to cover a state or region. The rules permit the retransmission of programs of other broadcast stations, subject to the usual requirement for consent of the originating station.

Eligibility in the "Instructional Television Fixed Service" is identical with that of the Noncommercial Educational Television Broadcast Service in being limited to nonprofit educational bodies.

Transmitter operation requires supervision by technically qualified operators, but routine operation may be conducted by radiotelephone third-class operators. There are also provisions for remote control and unattended operation of certain equipment.

Major manufacturers of equipment which currently install systems for this service are Adler Educational Systems Division of Litton Industries, New Rochelle, N. Y.; Electronics, Missiles and Communications, Inc., Mt. Vernon, N. Y.; Microlink Corporation, Copaigue, N. Y., and Radio Corporation of America, Camden, N. J.

A simple form (FCC Form 330P) is used by nonprofit educational organizations in applying for Commission authority to construct an "Instructional Television Fixed Service" station.

* Since this original FCC release, the number of channels in each channel group has been reduced to four channels with the exception of Channel Group H, which provides a group of three channels.

-FCC-

THE ESTABLISHMENT OF AN FCC COMMITTEE FOR THE FULL DEVELOPMENT OF INSTRUCTIONAL TELEVISION FIXED SERVICE

In 1965, the Federal Communications Commission established a nationwide committee of educators and educational television representatives to provide for the full development of the Instructional Television Fixed Service.

This full committee is chaired by Commissioner Robert E. Lee with Dr. Robert L. Hilliard, Chief of the Educational Broadcasting Branch of the FCC as Executive Vice Chairman.

One of the first acts of the committee was to establish four geographical regions within the continental United States to provide machinery for channel-group coordination between qualified applicants and to provide continuous liaison with the commission relating to problems, needs, and developments of ITFS plans throughout the U.S.

The regional committees are as follows:

1. Northeast Regional Committee, Chairman: Bernard Cooper
2. Southern Regional Committee, Chairman: William Smith
3. Midwest Regional Committee, Chairman: Lawrence Frymire
4. Western Regional Committee, Chairman: Alan Fink

In addition the FCC appointed the Rev. John Culkin Chairman of the National Groups. An Executive Committee has also been established composed of the above named Regional Chairmen, Mr. Lewis Rhodes of the National Association of Educational Broadcasters, and Dr. Harold Wigren of the National Education Association. Commissioner Robert E. Lee is Chairman of the Executive Committee and Dr. Hilliard is Executive Vice Chairman.

This is a unique administrative concept and holds great promise for the orderly development of this new instructional television service.

APPENDIX C

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